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OBLIQUE INCIDENCE OF COUPLING OF ACOUSTIC ENERGY

PHASE I: ACOUSTIC PROPAGATION THROUGH AIR/EARTH INTERFACE

FINAL REPORT

By

HERBERT S. ANTMAN

OCTOBER 1970

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

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EDO CORPORATION

COLLEGE POINT, N.Y. 11356

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NEW YORK

FOR

U. S. ARMY ELECTRONICS COMMAND, FORT MONMOUTH, N. J.

ABSTRACT

The purpose of this program was to investigate the feasibility and develop techniques for air-coupling acoustic energy into and through the soil. Acoustics, as well as mechanical probes, thermal detectors, aerial photography, infrared scanners, gravimetric anomaly, microwave radiometry and sonic techniques, have been used previously in experiments to establish their characteristics for propagation through the soil. Possible application of acoustic propagation in soil includes usage in detection, surveillance, or communications. The reason for pursuing acoustics is that until now certain key modes of propagation have been overlooked eg., the shear wave, which has great penetration capability and can sensitively respond to ground stress anomalies. This program then was to investigate acoustic energy propagation with an emphasis on shear wave propagation and air-coupling for obtaining practical mobility in any intended application.

Within the framework of the Edo study, a Phase I program was established to analyze and measure air attenuation coefficient, air/earth interface attenuation and propagation losses in a variety of soil types to depths of up to 25 feet and in the 1 - to 5-kHz acoustic frequency range. Oblique incidence of coupling of acoustical energy into and through the soil as determined by this investigation is considered to be a highly practical method of propagation and useful for the outlined applications.

Particularly the air coupling techniques developed in this program proved satisfactory and clearly established the feasibility of propagation through the air/earth interface. Further work in development and testing of mobile equipment is recommended.

FORWARD

The author is grateful for the cooperation and guidance of Mr. J. Walker, Captain W. Barney of Ecom/Evans and Dr. K. Ikrath of Ecom and Mr. A. Zanella. The experimental program was accomplished at the geophysical test range at Evans Area, Fort Monmouth, N. J.

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INTRODUCTION

Acoustic pressure waves generated by high-power sonar systems are propagated over great ranges in water. Returning echoes from distant underwater objects are detected, localized and classified despite the extensive signal losses inherent in water transmission and reception. Many factors indicate that acoustic wave propagation is possible in the soil. For example, the propagation parameters for density and velocity in soil and water are similar. The specific gravity of moist loose earth is 2.0-2.5, while that of water is 1.0, and the velocity of sound in many soils is 4400 feet/second, while it is 4800 feet/second in water (References 1 and 2). Another indication of acoustic propagation into soil is shown in figure 1, where a marine type sonar, located on the water surface and 14,000 feet above the earth's floor, produced sound waves which penetrated several hundred feet into the earth's substrata with enough energy to return excellent strata indications. Experiments have shown that the sounds produced by a sledge hammer can be heard by a human observer listening with an ordinary stethoscope some 3000 feet away through hard rock, 2000 feet away through coal, 400 feet away through clay, and 550 feet away through mine cover (Reference 3). With present day sonar technology, the sledge hammer can be replaced by a high energy reproducible acoustic waveform generator and the human observer can be augmented by sophisticated signal processing equipment.

In examining the application of present sonar technology, a first consideration is to establish the methods for coupling the acoustic energy to the soil and then test the propagation. Methods previously explored are referenced in the "Selected Bibliography," of this report. Edo Corporation has now completed a Phase 1 research investigation related entirely to: "Propagation of Acoustic Signals from the Air to-and-thru the Air/Earth Interface". The program plan included the following specific items:

1. Analyse transducer to air matching and beam formation using modeling techniques.

2. Fabricate experimental transducers and breadboard acoustic generator in the 1- to 5-kHz acoustic frequency range.

3. Determine air attenuation coefficients, air/earth interface attenuation (reflection coefficient) and propagation losses in a variety of soil types up to 25 feet in the 1- to 5-kHz acoustic frequency range.

Items 1 and 2 of the program were accomplished fully, while item 3, because of specific research difficulties, was only partially accomplished. The general progress of this study is summarized as follows:

* Obtained underground acoustic propagation from an air-coupled source:

  a) with a five-inch, air-coupled separation
  b) to a lateral range exceeding 20 feet
  c) along an oblique underground path 3 feet deep
  d) at frequencies from 50 Hz to 5000 Hz

* Developed tests for detecting unwanted cross talk, both electromagnetic and acoustic.

* Developed techniques for preventing and eliminating cross talk, both electromagnetic and acoustic.

* Developed tests for identifying the underground acoustic propagation modes, shear and pressure.

* Analyzed transducer-to-air matching and beam formation, using modeling techniques.

* Fabricated experimental transducers and breadboard acoustic generators operating in the 1- to 5-kHz acoustic frequency range.

* The actual determination of attenuation coefficients, air/earth interface attenuation (reflection coefficient) and propagation losses in a variety of soil types to depths of up to 25 feet in the 1- to 5-kHz acoustic frequency range was partially accomplished. The necessity to perform many of these measurements outdoors under complete exposure to subzero temperatures, snow and high winds, caused electronic failures, accidents and illness to personnel and delayed the program, precluding completion of this measurement.

ANALYSIS OF PROPAGATION

In compliance with the program objectives of transducer-to-air matching and beam formation, extensive study was made of the literature and conferences with laboratory personnel at ECOM. As a result, the following basic principles were evolved regarding underground acoustic propagation. Details of the analysis are presented in later sections of this report.

When a pressure wave is generated above the ground it couples to the earth and generates a pressure and a split beam shear wave. As the waves propagate away from the source, interference takes place between the shear and pressure waves. At still greater distances, surface Rayleigh waves continue to propagate (Reference 4). These waves travel only along the free

surface of an elastic solid. The particle motion, always in a vertical plane, is elliptical and retrograde with respect to the direction of propagation.

Since the ground supports both pressure and shear waves while any air void, such as a cavern, sinkhole or tunnel support only pressure waves, the acoustic impedance mismatch and therefore acoustic reflections will be much greater from the shear wave. Likewise, acoustic standing wave patterns would be more dramatically effected by the shear wave than the pressure wave. This points out the importance of experimentally identifying the propagation mode. Three tests were postulated for this experimentation:

Velocity Test
The shear wave velocity (1-3000 ft/sec) is less than the pressure wave velocity (5-10,000 ft/sec).

Intensity Test
The shear wave amplitude should be greater several feet under the ground than the pressure wave near the surface.

Phase Test
a) The phase balance between two receptors and one transmitter should be dramatically altered by the introduction of an air void (hole in the ground) if a shear wave is present.

b) Alternatively, one receptor between two transmitters can be used for this test.

EXPERIMENTAL PROGRAM

Determining whether high frequency acoustic energy will propagate through the ground from an air-coupled separation required experimentation in both lateral and vertical propagation paths. The lateral path was, however, the primary subject of investigation because the strong excitation of the shear wave mode was considered essential for this propagation, and provides the means for identification of ground stress anomalies caused by air voids.

Lateral Propagation Test Range and Equipment

The lateral test range was established in a quiet field at the ECOM-EVANS area and the electronic equipment was housed in an adjacent army truck. A pictorial layout is shown in figure 2. A lateral path length of 25'9" was used. It was experimentally determined by compromising between a range long enough for tunnel detection over twenty feet, and short enough for good signal reception. A second lateral path of 21'9" was used for auxiliary signal monitoring. An oblique transmission path was created by locating the receiving geophone four inches below the transmitting loudspeaker. However, a rather unusual arrangement was used to air couple the speaker to the ground without direct air coupling

between the speaker and the geophone: both were buried in holes with small air pockets around the speaker and geophone. Thus, air still coupled the speaker to ground, while filling in the hole above the speaker, baffled it, and prevented direct air coupling to the geophone.

A block diagram of the electronic transmission/reception system is shown in figure 3. A CW oscillator, power amplifier and loudspeaker comprise the transmitter. Two transmitters could be used: a 25-watt unit or a 100-watt unit. The receiver was comprised of a geophone, transformer coupled to an operational amplifier, a tuned amplifier and a dual-trace oscilloscope. The transformer-operational amplifier combination provided balanced two-wire operation for the geophone as well as high common mode noise rejection. The operational amplifier, figure 4, was constructed at Edo Corporation and provided wide band amplification (50 Hz to 5000 Hz) and a gain of 30 db for input signals up to 0.2 VRMS. A tuned amplifier was used to provide high signal detection of the CW signal (a wave analyzer was used as a tuned voltmeter for this purpose). The dual-trace oscilloscope was used to simultaneously monitor the transmitter electrical drive and receiver output. Time comparison was achieved by synchronizing channel B from the channel A signal.

Lateral Measurements

Received signal outputs were monitored on two occasions by recording the wave analyzer outputs on the oscilloscope and later reduced to the equivalent sound pressure inputs to the geophone. Tables 1 and 2 summarize the oscilloscope recorded data (Appendix A). Tables 3 and 4 summarize the reduced data for the wave analyzer input voltages, and tables 5 and 6 the reduced data for the geophone input velocity.

Since the normal signal output was much greater than under the open circuit, short circuit and dummy load conditions, true signal propagation through the ground was confirmed. The acoustic propagation, plotted in figure 5, clearly indicates the feasibility of high-frequency propagation.

The data fits the exponential $1.22 \times 10^{-10} f^{1.85}$ extremely well, within 5 percent from 250 Hz to 3000 Hz on two occasions and from 250 Hz to 5000 Hz on one occasion. This type of increase with frequency is characteristic of scattering phenomena and has been observed in sound transmitted through water and back scattered from the ocean bottom (Reference 5). With reference to bottom back scattering strength over a sandy bottom, a frequency increase to the 1.6 power was observed. Increased signal level with frequency has also been observed in transmission through ice (Reference 6). Here, superior quality transmissions were obtained at high frequencies (250 Hz and 1000 Hz) relative to low frequency (88 Hz).

The propagation loss has been calculated (Appendix B) from the ratio of intensity levels at the air interface, 6 inches from the source, and the received intensity level at the geophone, 25

feet, 9 inches (7.85 meters) away. Its value lies between 90 and 140 db over the 100 to 5000 Hz band. This includes air interface loss at the source which can be calculated from a simplified model of an ideal fluid and solid in contact at a rigid boundary. The transmitted compressional wave energy at normal incidence across the interface is (Reference 7):

$$I_t/I_i = 4R/\ (1 + R)^2$$

where

I_t = transmitted intensity

I_i = incident intensity

R = acoustic impedance ratio in transmitted medium to incident medium

The acoustic impedance is density times velocity. Since the sound velocity in soil is close to that in air (Reference 2), we can approximate the impedance ratio by the density ratio. Further noting that this ratio is much greater than unity, we have:

$$I_t/I_i = 4\ \rho_i/\rho_t$$

where

ρ_i/ρ_t is the air-to-soil density ratio.

Since

ρ_t = 2.7 g/cc, wet soil density of the tertiary Kirkwood soil at test site,

and

ρ_i = 1.3×10^{-3} g/cc, air,

we have

$$I_t/I_i = 4 \times 1.3 \times 10^{-3}/2.7$$
$$= 1.93 \times 10^{-3}$$

or an air interface loss of 27 db. This results in about 14 db/meter propagation loss in the soil at 100 Hz and lies in a range found by experiments for the near zone shear wave in permafrost (Reference 4). Further investigation is required to identify this mode of propagation clearly.

To determine the extent of subsurface propagation as opposed to surface propagation, a comparison of the received signal levels was made with a surface geophone and one directly below it (40 inches). This was done at both hole locations and the results are recorded in table 7. The results indicate a comparable signal level for the far hole and a reduced subsurface signal level in the near hole. Thus, a substantial transfer of acoustic energy took place near the surface rather than below.

The same simplified model is again offered to explain the low subsurface signal level, i.e., an ideal fluid and solid in contact at a rigid boundary. The transmitted compressional wave

energy across this boundary at normal incidence is again:

$$I_t/I_i = 4R/\ (1 + R)^2.$$

The acoustic impedance is density times velocity. Since the density of ice is so close to that of water, 92 percent, we can assume approximately equal densities of the frozen and unfrozen wet soil, so that the impedance ratio can be approximated by the velocity ratio. The longitudinal wave velocity in ice is (Reference 7) 11,500 ft/sec. Assuming a soil velocity of about half this, the transmitted energy is about 90 percent of the incident energy. Thus most of the energy is transmitted across the boundary. Indeed, this condition prevails over a wide range of impedance ratios: e.g., 1/2 - 2. If in addition to this efficient coupling to the frozen soil a very low attenuation relative to the natural soil also exists, there will be a greater transmission to the surface geophone than the subsurface one.

Vertical Propagation Test Range and Equipment

An electronic geophysical laboratory was fabricated and instrumented for the purpose of investigating the acoustic propagation of audio frequencies through the air and into the earth.

Pressure waves were generated from several types of transmitting and receiving transducers. Their separation was along a vertical line with the receiving transducer underground and the projector on and above the ground. Signals were received from an air-coupled projector, up to 6 inches above the ground, to an underground receiving microphone 12 inches below the ground. Measurements were made using a pulsed CW source driving a piezoelectric AN/UQC transducer. A block diagram of the measurement equipment is shown in figure 6. The measured data (Appendix A) is plotted in figure 7 and clearly illustrates the propagation and relative attenuation for various earth penetrations and air separation.

The voltage outputs can be related to the received ground displacement by the microphone's calibration, figure 8. This indicates a decreasing input/output amplitude response with frequency (an approximate curve fit indicates an exponential decrease to the 2.5 power of frequency). Since the received voltage level is relatively constant with frequency, the ground displacement at the microphone input decreases with frequency.

The propagation loss can also be deduced by relating the received power to the transmitted power. Since power is proportional to displacement squared, we have a received power level that decreases with frequency (approximately as the fifth power of frequency). The electrical drive to the transmitting transducer was held constant with frequency. However, the characteristic of the AN/UQC transducer below resonance provides an exponential rise with frequency for a constant electrical drive. The propagation loss, transmitted power/receiver power, then increases exponentially with frequency.

A comparison of the two penetrations is presented in figure 7.

Several conclusions may now be drawn:

1. Propagation is obtained throughout a 5-kHz band. The loss increases exponentially with frequency.

2. The propagation loss increases with the receiver microphone's depth. This loss is approximately 16 times higher at 12" depth than 6". Spherical spreading would account for a loss factor of 4. The additional factor of 4 could be caused by soil attenuation and/or scattering.

3. The propagation loss decreases slightly with projector height. This may be caused by near field operation of the projector and microphone. Irregularities in the responses may be due to multipath interferences as well as airborne standing waves.

4. The frequency response becomes smoother at increased soil depths. Variations in the propagation loss diminish at approximately the same rate (16) as the propagation loss increases. This is to be expected since decreasing signal amplitude proportionately decreases the signal amplitude variations.

These initial experiments were exploratory in nature, using several types of sound sources. Those experiments indicated that sound can be coupled through the air/earth interface in the audio frequency range with losses in the vicinity of 15 to 20 db.

The projector transducers used were:

A. ECOM electrodynamic (figure 9).

B. Edo-fabricated piezoelectric mass-loaded stack (figure 10).

C. Edo Profiling Transducer (figure 11).

D. Edo ceramic ring (figure 12).

E. Edo ceramic piston AN/SQS-26 (figure 13).

F. Loudspeaker Driver-High Power (figure 14).

G. Loudspeaker Driver-Low Power (figure 15).

The microphone transducers used were:

A. Electrodynamic geophone (figure 16).

B. Piezoelectric Microphone.

C. Piezoelectric LC 10 hydrophone.

NOTE

Calibrations appear in Appendix C

MEASUREMENT PROBLEMS AND THEIR SOLUTION

Problems encountered are described in four main groupings.

1. a) Unwanted electromagnetic coupling between transmitter and receiver.

   b) Signal loss and false signal gain due to short circuiting by snow and its condensation at electrical connectors at geophones and speakers.

2. Unwanted acoustic coupling between transmitter and receiver via a lateral airborne path instead of a lateral underground path.

3. Inclement weather - snow, cold, subzero temperatures, high winds, etc. (No solution; ultimately prevented further work on this program phase.)

4. High ambient noise background:

   a) near airport and other vehicular traffic

   b) during wind or precipitation

Specific tests were established to certify data validity against any unwanted coupling and a quiet location was chosen, ECOM/EVANS, to minimize the vehicular noise problem encountered in New York City.

Data Validity Tests

The following test criteria were established to determine the presence of electromagnetic and acoustic measurement problems.

Electromagnetic

1. No reception should be obtained when the geophone is replaced by a short circuit or dummy load. The dummy load was a resistor comparable to the geophone coil resistance.

2. No reception when the speaker is replaced by a short or open circuit.

Note

To facilitate tests 1 and 2, quick-disconnect plugs (GR types) were used at the geophone and loudspeaker. To cope with signal loss and false signal gain caused by snow and its condensation, these connectors were wrapped in plastic bags. Condensation within the bags and their apparent conductivity in the snow and 20-degree operating

temperatures caused intermittent reception. Additional insulation was obtained by plugging the connectors into urethane blocks.

3. No reception when the speaker is acoustically baffled (muted).

4. Reception should be obtained when an electromagnetic shield (MU metal) is introduced between the speaker and the geophone.

Acoustic

1. The signal reception should remain constant when the signal in the lateral airborne path is varied and the transmitter signal is held constant. This can be done by introducing an amplifier or attenuator into the airborne path. Wooden planks were used in this test to introduce attenuation between the speaker and geophone.

2. The underground geophone signal should be much greater than that of an above-ground geophone. The above ground geophone was mounted in a urethane foam and placed on the ground directly above the underground geophone hole.

Decoupling Techniques

Electrical

These signals were decoupled by: 1) driving the speaker with a two-wire shielded cable from an ungrounded transformer output. The speaker case was not connected. The shield was grounded to one side of the input to the transformer, which was also connected to the power line ground. 2) Receiving the geophone signals from a two-wire shielded cable to a transformer whose secondary drives a differential operational amplifier. The cable's shield is tied to the secondary center tap and grounded. 3) Avoiding spurious oscillation frequencies. (Appendix C)

Acoustic

Both the geophone and speaker were placed underground at the bottom of a pair of 3-foot holes. The geophone was implanted at the bottom of its hole, but the speaker was suspended by a string above the bottom of its hole to insure air coupling to the ground. The holes were then filled with acoustic damping material with special care taken to avoid pressure loading the top of the geophone and also to avoid filling the air space under the speaker. Various acoustic damping materials were tested: Kapok, Styrofoam, urethane, foam rubber, soil-filled polyethelene bags and finally sand-filled polyethelene bags. The sand was by far the most effective sound dampener.

Coupling Techniques

When the speaker is suspended above the ground, an acoustic standing wave is generated by the interference from the ground reflection and the speaker transmission. At certain heights (odd multiples of a quarter wavelength), the output is nullified. This was easily observed by manually varying the speaker's height and listening to its output. Thus, to maintain the full available acoustic-output, these operating heights were avoided.

CONCLUSIONS

Underground acoustic propagation from an air-coupled source under the conditions of this investigation was successfully accomplished:

1. With a five-inch air-coupled separation.

2. To a lateral range exceeding 20 feet.

3. Along an oblique underground path 3 feet deep.

4. At frequencies from 50 Hz to 5000 Hz.

Lateral propagation increasing with frequency is consistent with other ECOM investigations. (Needs further investigation.)

The large magnitude of propagation loss measured in the experiment characterizes a shear wave (near zone) propagation as defined by other ECOM experiments. This conclusion requires further study.

Of the various transducers tested, optimal results from air coupling were obtained from a loudspeaker and from a piezoelectric ring (AN/UQC transducer element). The loudspeaker results were superior to all other transducers used in the experiment.

RECOMMENDATIONS

The present program has proven the feasibility of and developed techniques for air-coupling acoustic energy into and through the soil. Additional experimental propagation loss data is required to quantitatively support the use of this propagation method for specific applications. Experimentation should be accomplished with Evans Area type soil as well as other soil types. Repeated testing with soil of the type at the Evans Area is necessary to obtain repeatability of data under varying soil conditions. Program objectives should definitely include developing techniques for propagating shear waves from above the ground without acoustic cross-coupling.

To realize this a quan.itative model is required for air/earth coupled sound propagation systems. Several investigators (Ikrath, Ewing) have developed mathematical models for ground/

ground coupling in elastic layered media which can form the basis for further extrapolation. Experimental data is then required to establish and verify the parameters of the analytic model. Computer simulation would be useful in determining the effect of all parameters; e.g., propagation loss, soil layer depth, attenuation coefficient. Finally, application for detecting and classifying targets (air cavities) should be made using echo sounding techniques. Areas of investigation are outlined below to meet these objectives:

ASDAC INVESTIGATION

(Air-coupled Sound Detection And Classification)

1. Mathematical Model

   A. Geometric parameters

      Soil layer depth
      Soil layer boundaries
      Source/Receiver location

   B. Medium parameters - Geophysical

      Layer composition (density, Young's modulus)
      Meteorological (temperature, humidity, precipitation, wind)

   C. Medium Parameters - Geoacoustic

      Layer acoustic impedance
      Layer acoustic velocity
      Boundary reflection/scattering coefficient
      Attenuation coefficient
      Ambient acoustic noise (coupled to ground)

   D. Electroacoustic Parameters

      Transmitted waveform
      Transmitted frequency, amplitude, phase
      Electrical noise (noise figure)
      Received signal/noise
      Received wavetype (longitudinal, transverse)
      Received waveform fidelity
      Received wave amplitude, frequency, etc.
      Mean value, mean variability
      Propagation loss
      Reverberation
      Sound Ray Paths

2. Computer Model

      ASDAC ranging equation model
      Sound ray path/normal mode model
      Reverberation model
      Propagation Loss model

3. Experimental Model - Electroacoustic

CW Transmission
Pulsed CW transmission

4. Tunnel Detection and Classification

A. Detection

Source/Receiver stationary
Source/Receiver moving

B. Classification

Spatial pattern recognition
Temporal pattern recognition

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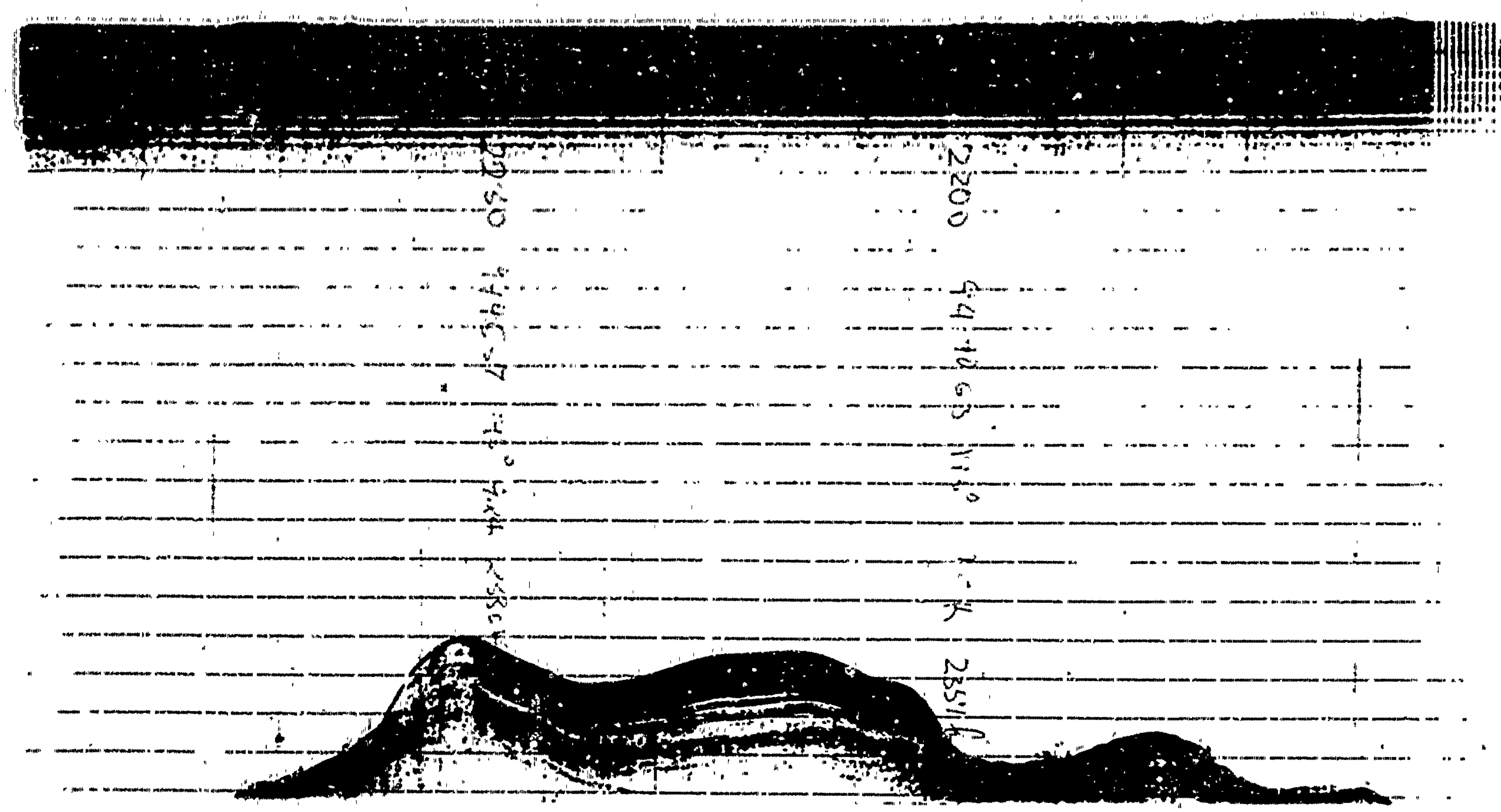


FIGURE 1
RECORDING OF THE BLAKE-BAHAMA RIDGE
(200 MILES EAST OF FLORIDA)
TAKEN BY EDO WESTERN'S MODEL 400 BOTTOM PENETRATION SYSTEM

OPERATING SCALE: 2000-2400 Fathoms
PRR: 1/second
PULSE WIDTH: 5 ms
RESEARCH VEHICLE: Lamont Lab's "Vema"

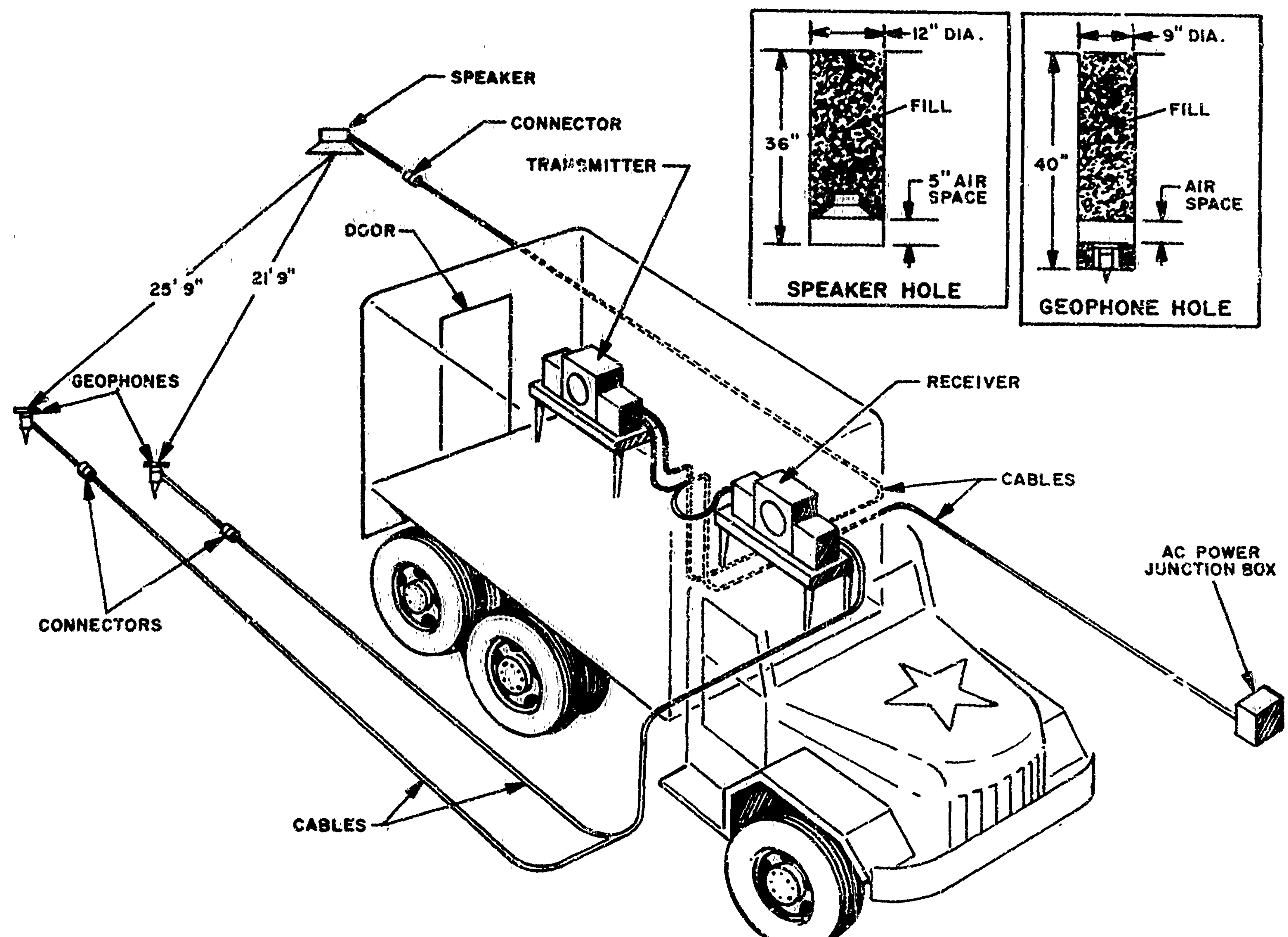


Fig. 2 Lateral Propagation Equipment Layout

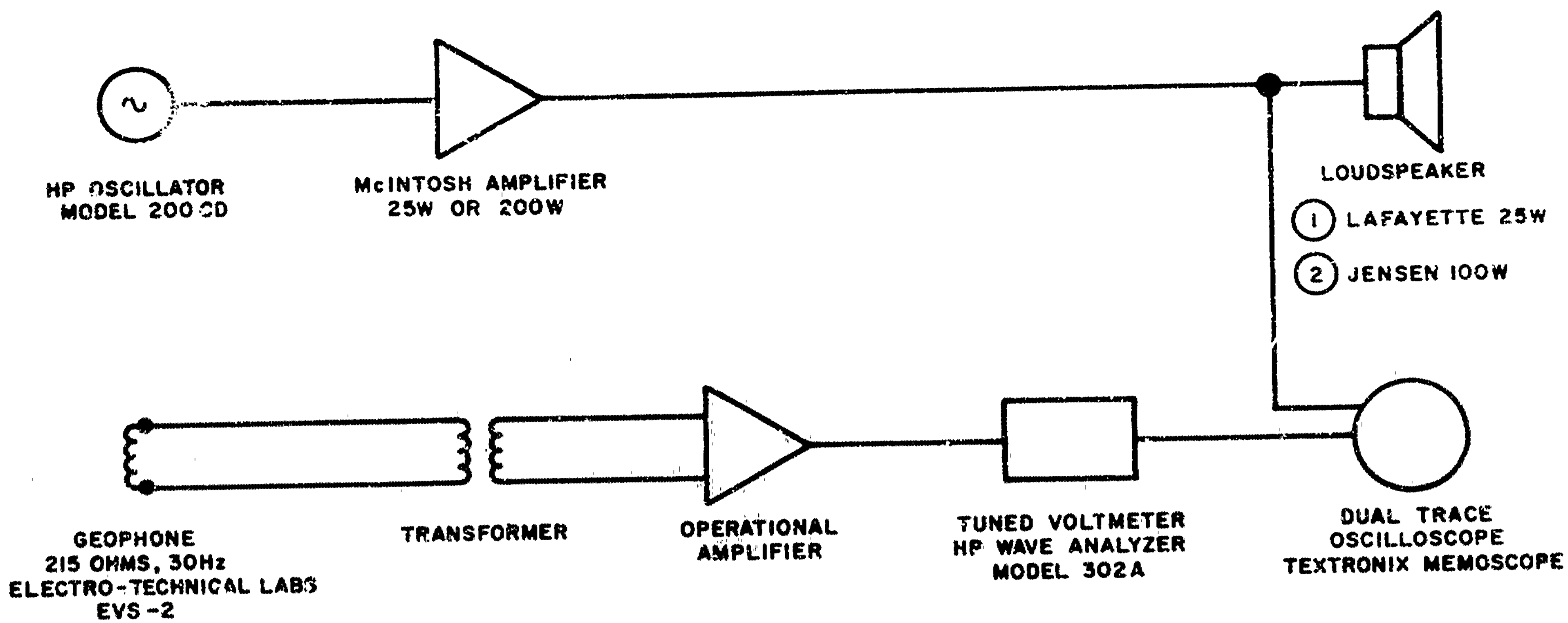
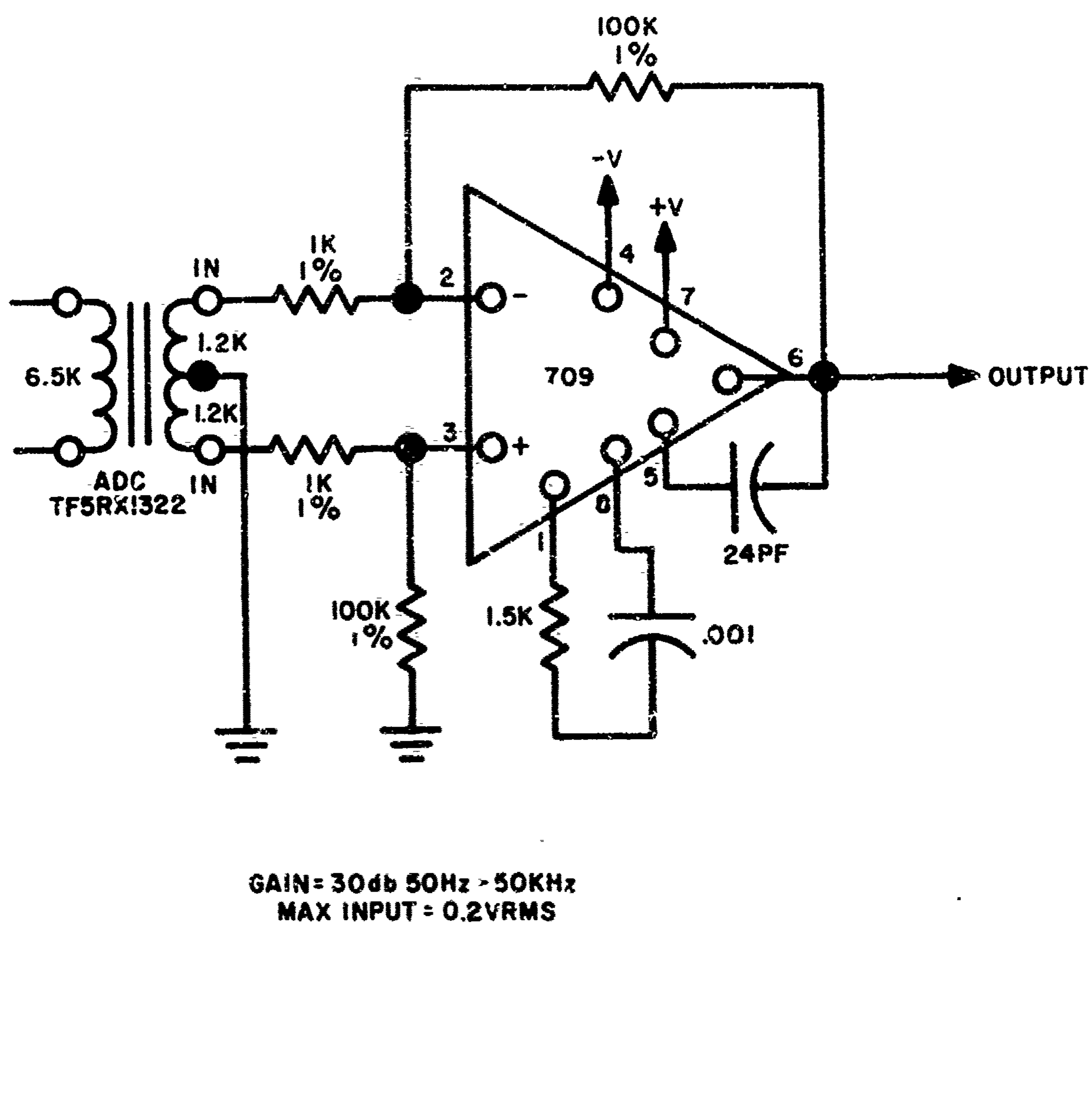


Fig. 3 Lateral Propagation Block Diagram



GAIN= 30db 50Hz - 50KHz
MAX INPUT = 0.2VRMS

Fig. 4 Operational Amplifier

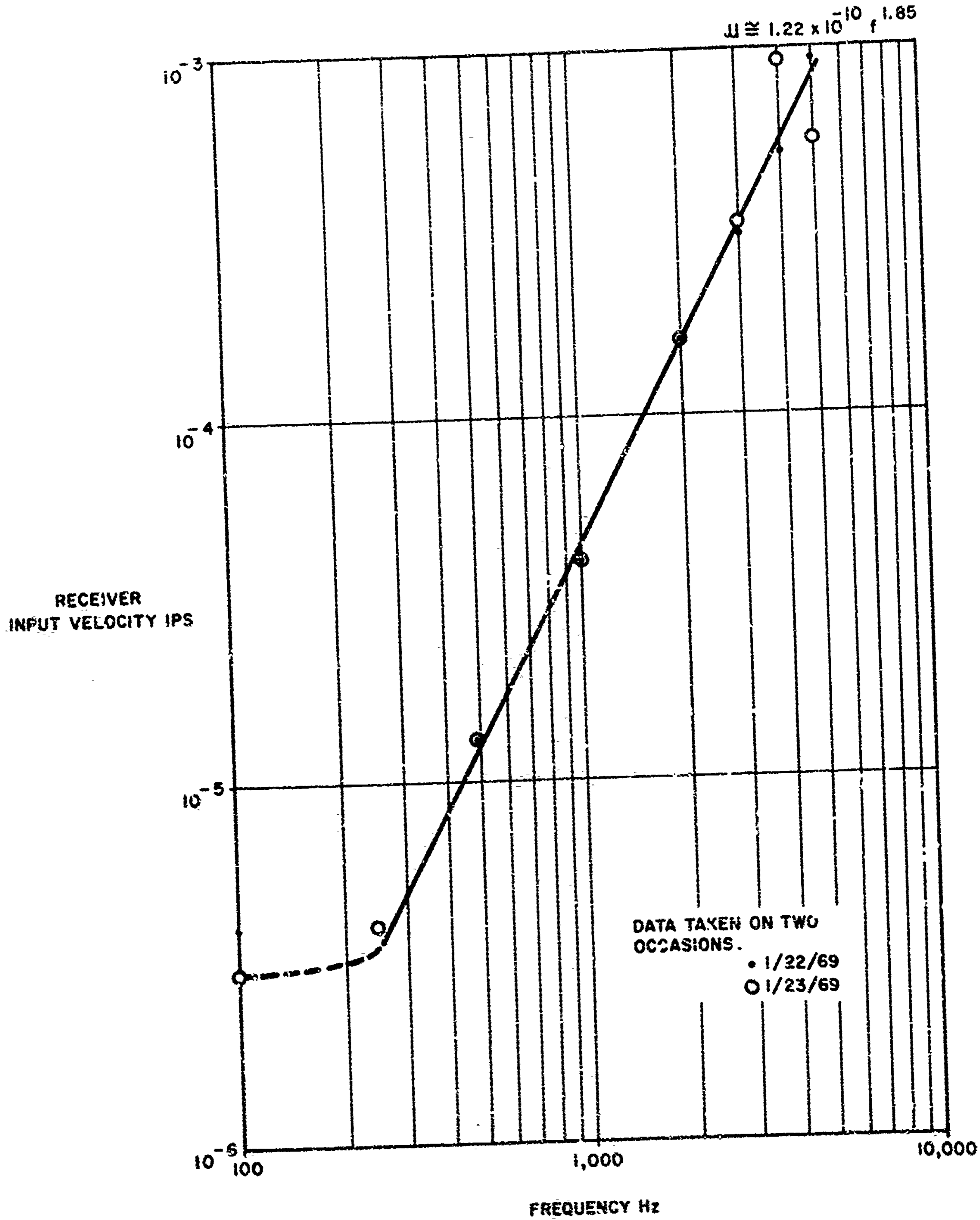


Fig. 5 Lateral Propagation Frequency Response

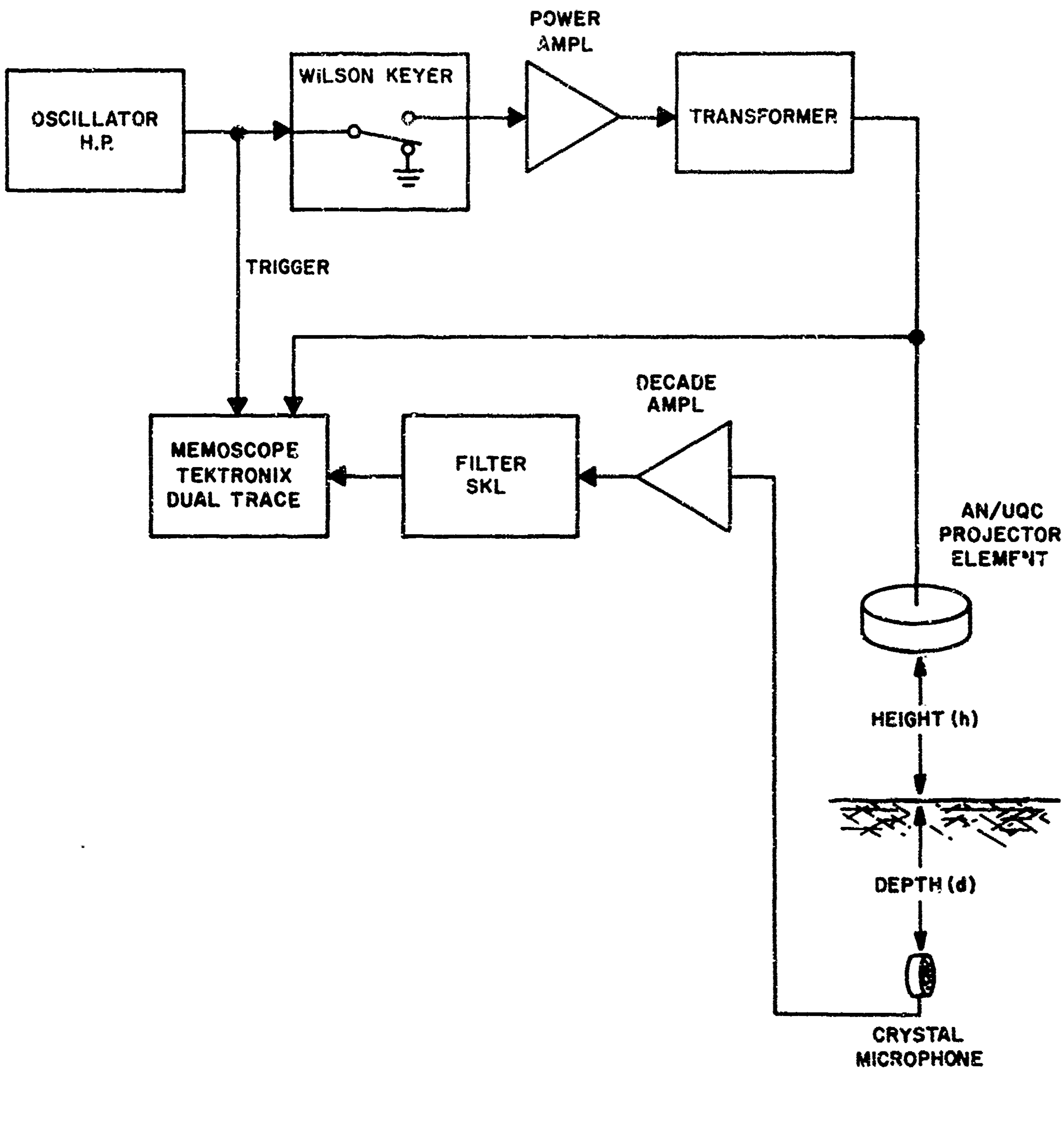


Fig. 6 Vertical Propagation Block Diagram

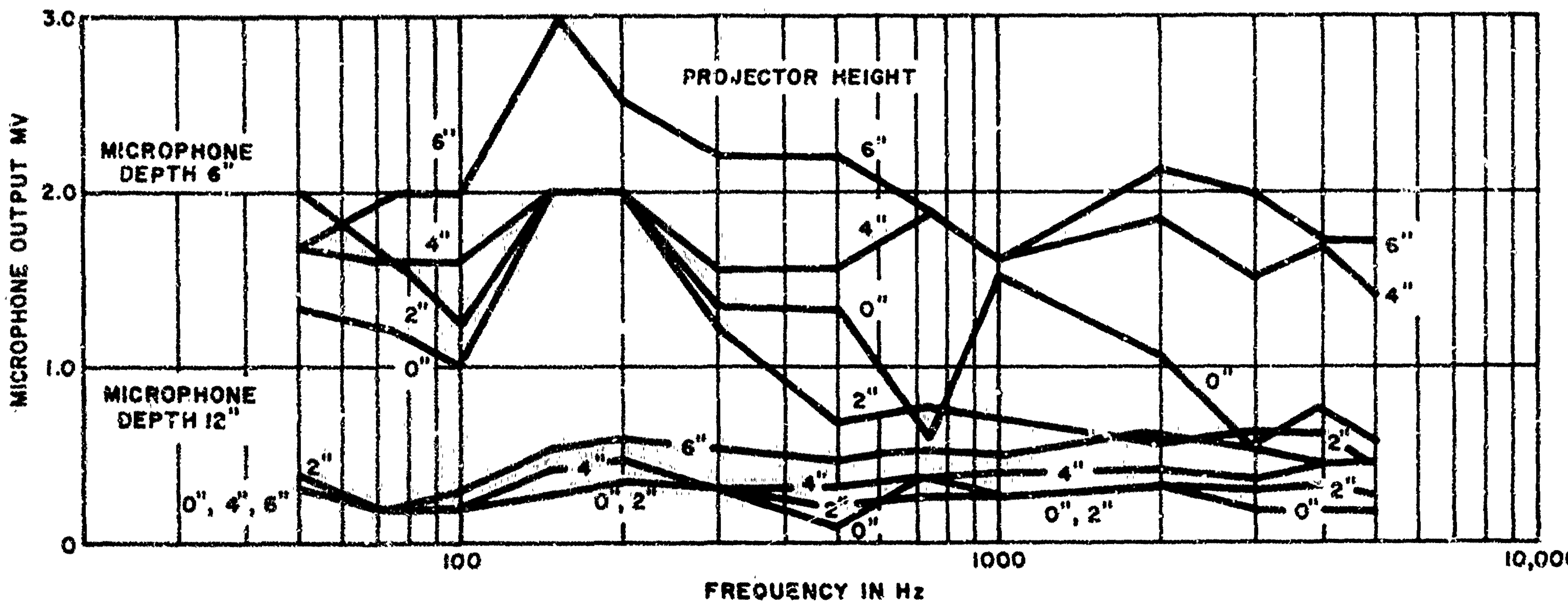


Fig. 7 Vertical Propagation Frequency Response

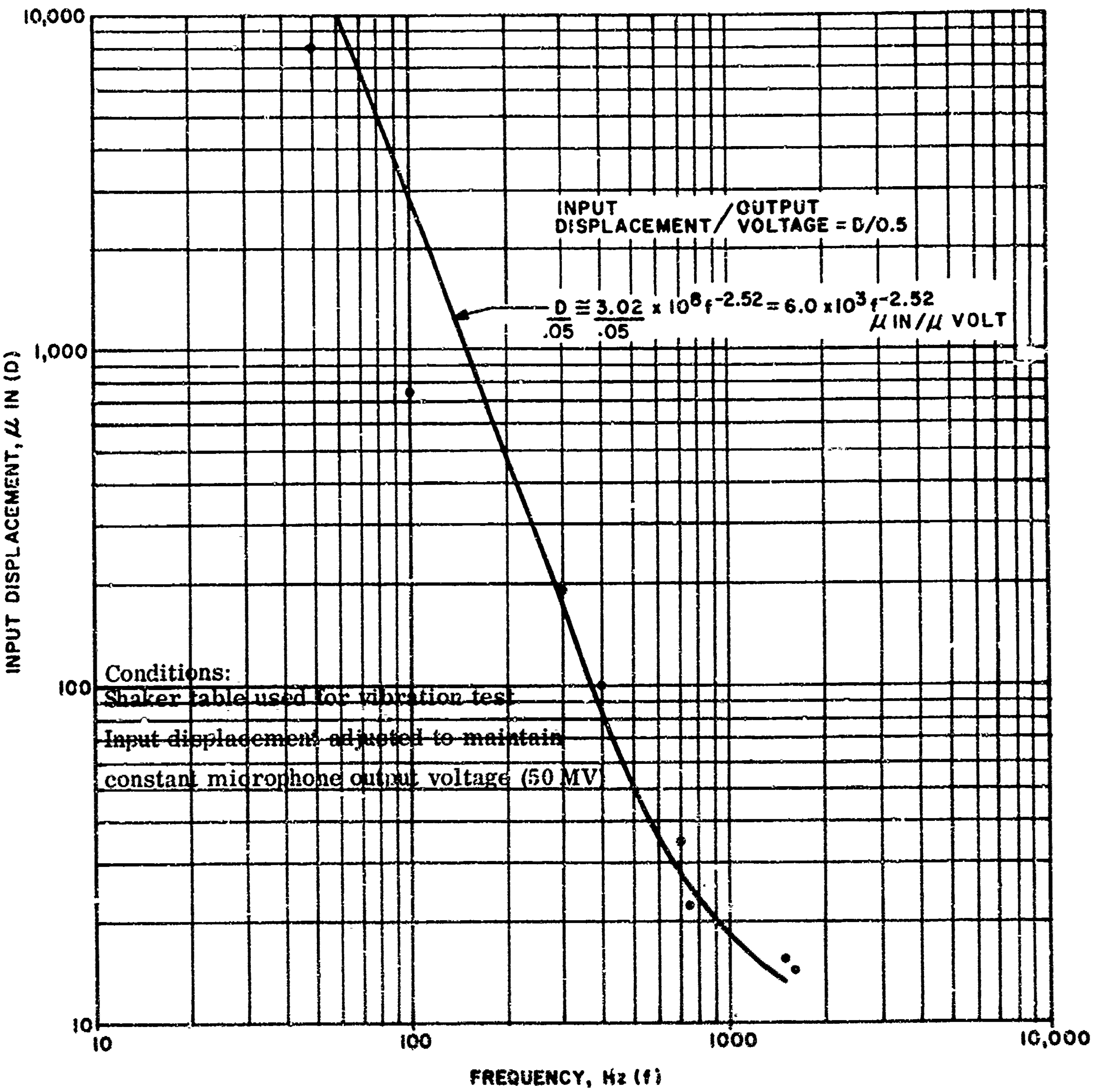


Fig. 8 Crystal Microphone Calibration

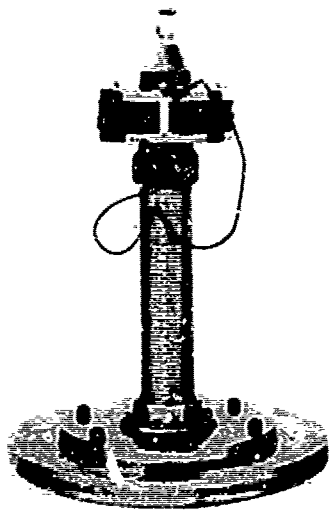


Figure 9. ECOM Electrodynamic Transducer

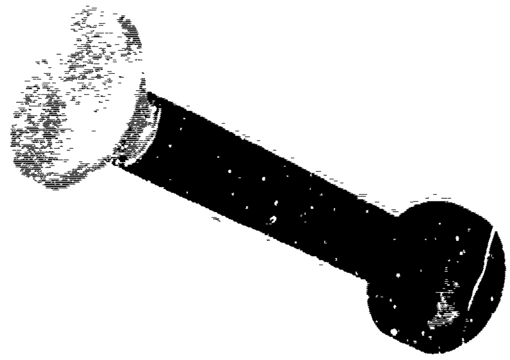


Figure 10. Edo Piezoelectric Mass-Loaded Stack

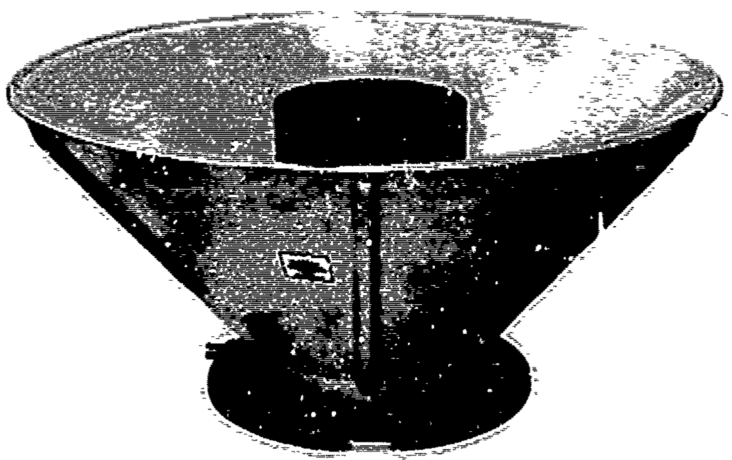


Figure 11. Edo Profiling Transducer

Figure 12. Edo Ceramic Ring, AN/UQC Element

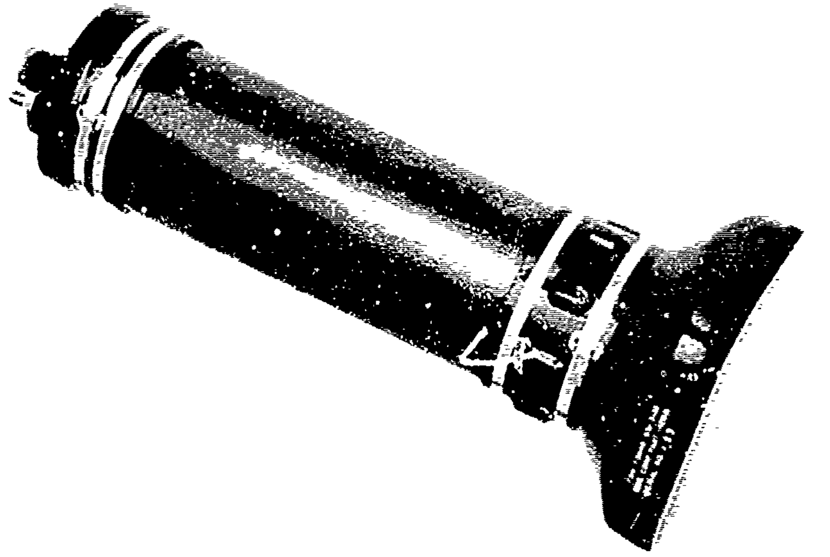


Figure 13. Edo Ceramic Piston.
AN/SQS-26

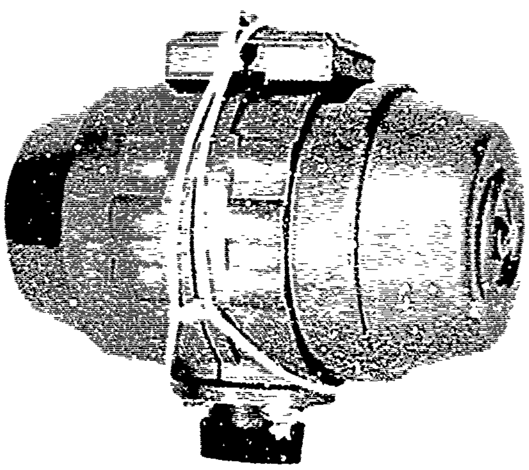


Figure 14. Loudspeaker Driver-
High Power

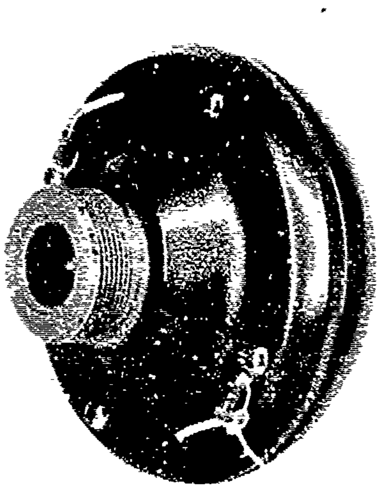


Figure 15. Loudspeaker Driver-
Low Power

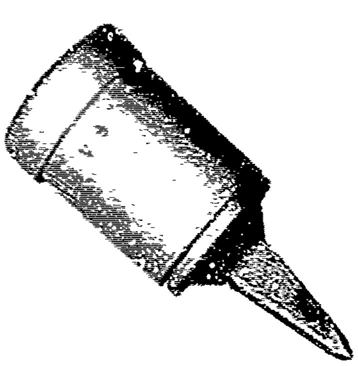


Figure 16. Elelctrodynamic Geophone

APPENDIX A

PROPAGATION DATA

PROPAGATION FREQUENCY RESPONSE TEST SETUP

Test Condition A* :

Spatial	Projector in hole 5 inches above bottom and 3 feet below surface.
	Geophones 20 feet and 25 feet away at bottom of 40 inch hole.
	Both holes acoustically insulated above transducers.
Electrical	Loudspeaker drive: 80 VPP.
	Loudspeaker impedance: 12.5 ohms.
Transducer :	UQC element. Receiver element: crystal.

Test Condition B**:

Spatial	Projector height above ground (inches): 0, 2, 4, 6
	Receiver depth below ground (inches): 6, 12.
Electrical	UQC drive: 200 VPP, except as noted
	Pulse repetition rate: 1.25 sec.
	Pulse width: 0.1 sec.
Transducer :	Loudspeaker, high power; receiving element, geophone

* Reference data tables 1 through 6 for data collected under test condition A.

** Reference data tables 8 through 15 for data collected under test condition B.

System linearity is assumed, Fig. A1 and the receiver output is normalized to 200 VPP projector drive. The microphone output voltage is then computed from

$$\text{microphone output (mv)} = \text{scope voltage} \times \text{filter input/output response} \times \text{amplifier gain} \times \frac{200 \times 10}{\text{Projector drive}}$$

where: scope voltage = scope voltage scale x deflection

amplifier gain = 10^2

SKL Filter input/output response, Fig. C2

SURFACE-SUBSURFACE PROPAGATION COMPARISON TEST SETUP

Test Condition***:

Spatial	Projector in hole 5 inches above bottom and 3 feet below surface.
	Four geophones 20 feet and 25 feet away at bottom and top of 40 inch holes.
	Both holes filled with acoustic insulation, but with small air gap above bottom geophone.
Electrical	Loudspeaker drive: 80 VPP
	Loudspeaker impedance: 12.5 ohms

*** Reference data table 7 for data collected under this test condition.

TABLE 1 - RECEIVER OUTPUT - WAVE ANALYZER OUTPUT

1/22/69

	Normal Output		Xmitter Open Ckt		Geophone Replaced by Dummy Load (82Ω)	
Freq (Hz)	Oscill (Volts)	Wave Anal. Rng. Scale (-db/volt)	Oscill (Volts)	Wave Anal. Rng. Scale (-db/volt)	Oscill (Volts)	Wave Anal. Rng. Scale (-db/volt)
100	1.5	90	2.0	90	1.0	90
250	2.0	90	0.6	90	0.4	90
500	2.0	80	1.4	90	0.3	90
1000	2.0	70	1.4	80	0.4	90
2000	2.4	60	1.6	70	0.4	90
3000	1.6	50	2.5	70	3.0	90
4000	1.4	40	1.6	60	3.0	90
5000	2.8	50	2.4	60	3.0	90

Conditions:

(1) Receiver output recorded by oscilloscope from wave analyzer output.

(2) Transmitter output voltage constant at 80 VPP.

TABLE 2 - RECEIVER OUTPUT - WAVE ANALYZER OUTPUT

1/23/69

	Normal Output		Output with Xmitter			Output with Geophone Replaced by		
Freq (Hz)	Oscill (volts)	Wave Anal Rng. Scale (-db/volt)	Open Ckt Scope (volts)	Analzr. Range (-db/volt)	Dummy Loaded (8 Ω)	Short Ckt	Anal Range (-db/v)	Dummy Load (82 Ω)
100	2.0	90	-	-	-	-	-	-
250	1.8	90	3	90	0.4	-	90	0.4
500	2.0	80	3	90	0.4	0.4	90	0.1
1000	2.0	70	3	90	1.0	0.4	90	0.4
2000	2.4	60	3	90	2.4	0.7	90	1.4
3000	1.6	50	3	80	1.4	1.7	90	0.9
4000	2.8	50	3	80	3.0	2.8	90	1.4
5000	1.4	40	3	60	1.5	4.0	90	2.0

Conditions:

(1) Receiver ouput refers to wave analyzer output.

(2) Transmitter output constant at 80 VPP when driving speaker.

(3) Transmitter output constant at 60 VPP when driving dummy load.

TABLE 3 - RECEIVER OUTPUT - OPERATIONAL AMPLIFIER OUTPUT

1/22/69

Frequency (Hz)	Normal Output (volts)	Output (volts) with Xmitter Open Circuited	Output (Volts) Replaced with Dummy Load (82Ω)
100	3.0×10^{-5}	4.0×10^{-5}	2.0×10^{-5}
250	4.0×10^{-5}	1.2×10^{-5}	0.8×10^{-5}
500	1.3×10^{-4}	2.8×10^{-5}	0.6×10^{-5}
1000	4.0×10^{-4}	0.93×10^{-4}	0.8×10^{-5}
2000	1.6×10^{-3}	3.2×10^{-4}	0.8×10^{-5}
3000	3.2×10^{-3}	7.0×10^{-4}	6.0×10^{-5}
4000	0.93×10^{-2}	1.07×10^{-3}	6.0×10^{-5}
5000	5.6×10^{-3}	1.6×10^{-3}	6.0×10^{-5}

Conditions:

(1) Receiver output refers to operational amplifier output.

(2) Transmitter output voltage constant at 80 VPP.

TABLE 4 - RECEIVER OUTPUT - OPERATIONAL AMPLIFIER OUTPUT

1/23/69

Frequency (Hz)	Normal Output (volts)	Output (volts) with Transmitter: Open Cir.	Output (volts) with Transmitter: Dummy Load[4] (8Ω)	Output (volts) with Geophone Replaced by: Short Circuit	Output (volts) with Geophone Replaced by: Dummy Load (82Ω)
100	4.0×10^{-5}	---	---	---	---
250	3.6×10^{-5}	6×10^{-5}	1.1×10^{-5}	---	0.8×10^{-5}
500	1.3×10^{-4}	6×10^{-5}	1.1×10^{-5}	0.8×10^{-5}	0.2×10^{-5}
1000	4.0×10^{-4}	6×10^{-5}	2.7×10^{-5}	0.8×10^{-5}	0.8×10^{-5}
2000	1.6×10^{-3}	6×10^{-5}	6.4×10^{-5}	1.4×10^{-5}	2.4×10^{-5}
3000	3.2×10^{-3}	2×10^{-4}	1.2×10^{-4}	3.4×10^{-5}	1.8×10^{-5}
4000	5.6×10^{-3}	2×10^{-4}	2.7×10^{-4}	3.6×10^{-5}	2.8×10^{-5}
5000	0.93×10^{-2}	3×10^{-2}	1.3×10^{-3}	8.0×10^{-5}	4.0×10^{-5}

Conditions:

(1) Receiver output refers to operational amplifier output.

(2) Transmitter output constant at 80 VPP when driving speaker.

(3) Transmitter output constant at 60 VPP when driving dummy load.

(4) Voltages normalized (multiplied by 80/60) for comparison with 80 VPP drive.

TABLE 5 - RECEIVER INPUT VELOCITY

1/22/69

Frequency (Hz)	Normal Input (ips)	Input (ips) with Transmitter Open Circuited	Input (ips) with Geophone Replaced with Dummy Load (82Ω)
100	3.0×10^{-6}	4.0×10^{-6}	2.0×10^{-6}
250	4.0×10^{-6}	1.2×10^{-6}	0.8×10^{-6}
500	1.3×10^{-5}	2.8×10^{-6}	0.6×10^{-6}
1000	4.0×10^{-5}	0.93×10^{-5}	0.8×10^{-6}
2000	1.6×10^{-4}	3.2×10^{-5}	0.8×10^{-6}
3000	3.2×10^{-4}	7.0×10^{-5}	6.0×10^{-6}
4000	0.93×10^{-3}	1.07×10^{-4}	6.0×10^{-6}
5000	5.6×10^{-4}	1.6×10^{-4}	6.0×10^{-6}

Condition:

Transmitter output voltage constant at 80 VPP.

TABLE 6 - RECEIVER INPUT VELOCITY

1/23/69

Frequency (Hz)	Normal Input (ips)	Input (ips) with Transmitter: Open Cir.	Input (ips) with Transmitter: Dummy Load (8Ω)	Input (ips) with Geophone Replaced by: Short Circuit	Input (ips) with Geophone Replaced by: Dummy Load (82Ω)
100	4.0×10^{-6}	------	------	------	------
250	3.6×10^{-6}	6×10^{-6}	1.1×10^{-6}	------	0.8×10^{-6}
500	1.3×10^{-5}	6×10^{-6}	1.1×10^{-6}	0.8×10^{-6}	0.2×10^{-6}
1000	4.0×10^{-5}	6×10^{-6}	2.7×10^{-6}	0.8×10^{-6}	0.8×10^{-6}
2000	1.6×10^{-4}	6×10^{-6}	6.4×10^{-6}	1.4×10^{-6}	2.4×10^{-6}
3000	3.2×10^{-4}	2×10^{-5}	1.2×10^{-5}	3.4×10^{-6}	1.8×10^{-6}
4000	5.6×10^{-4}	2×10^{-5}	2.7×10^{-5}	3.6×10^{-6}	2.8×10^{-6}
5000	0.93×10^{-3}	3×10^{-4}	1.3×10^{-4}	8.0×10^{-6}	4.0×10^{-6}

Conditions:

(1) Transmitter output constant at 80 VPP when driving speaker.

(2) Transmitter output constant at 60 VPP when driving dummy load.

(3) Voltage normalized (multiplied by 80/60) for comparison with 80 VPP drive.

TABLE 7 - RECEIVED SIGNAL COMPARISON ON THE SURFACE AND BELOW

Geophone Depth below Surface (in.)	Oscilloscope Output (volts)	Wave Analyzer Range Scale (db/volt)	Operational Amplifier Output (volts)	Distance between Geophone and Loudspeaker
0	2.0	-10	0.42	25' 9"
40	2.0	-10	0.42	25' 9"
0	4.0	-20	0.267	21' 9"
40	1.0	-40	0.0067	21' 9"

TABLE 8

Nov. 24, 1969

RECEIVER OUTPUT
MICROPHONE 6" BELOW GROUND
PROJECTOR ON GROUND

weather
clear
temp. 30's
dry

Frequency Hz	Oscilloscope Voltage Scale Volts/Div	Oscilloscope Deflection Divisions	a Voltage PP	Projector Drive Volts PP	b Filter Response In/Out	c Projector Normalizing Factor Proj. 200/Drive	column axbxcx10 Microphone Output MV
50	0.02	6.0	0.12	200	1.67	1.00	2.00
75	0.02	4.0	0.08	200	2.00	1.00	1.60
100	0.02	3.0	0.06	200	2.00	1.00	1.20
150	0.02	4.0	0.08	200	2.50	1.00	2.00
200	0.02	4.0	0.08	200	2.50	1.00	2.00
300	0.02	6.0	0.12	200	1.11	1.00	1.33
500	0.02	6.0	0.12	200	1.11	1.00	1.33
750	0.02	2.5	0.05	200	1.17	1.00	0.585
1000	0.05	3.0	0.15	200	1.00	1.00	1.50
2000	0.02	4.0	0.08	200	1.33	1.00	1.064
3000	0.02	2.0	0.04	200	1.25	1.00	0.500
4000	0.01	3.0	0.03	200	1.41	1.00	0.423
5000	0.01	3.0	0.03	200	1.41	1.00	0.423

TABLE 9

Nov. 25, 1969

RECEIVER OUTPUT

MICROPHONE 6" BELOW GROUND

PROJECTOR 2" ABOVE GROUND

weather
clear
temp 40's
dry

Frequency Hz	Oscilloscope Voltage Scale Volts/Div	Oscilloscope Deflection Divisions	a Voltage PP	Projector Drive Volts PP	b Filter Response In/Out	c Projector Normalizing Factor Proj. 200/Drive	column axbxcx10 Microphone Output MV
50	0.02	4.0	0.08	200	1.67	1.00	1.34
75	0.02	3.0	0.06	200	2.00	1.00	1.20
100	0.02	2.5	0.05	200	2.00	1.00	1.00
150	0.02	4.0	0.08	200	2.50	1.00	2.00
200	0.02	4.0	0.08	200	2.50	1.00	2.00
300	0.02	5.5	0.11	200	1.11	1.00	1.21
500	0.01	6.0	0.06	200	1.11	1.00	0.67
750	0.01	6.0	0.06	200	1.17	1.00	0.77
1000	0.01	7.0	0.07	200	1.00	1.00	0.70
2000	0.01	6.5	0.06	200	1.33	1.00	0.56
3000	0.01	5.0	0.05	200	1.25	1.00	0.62
4000	0.01	4.2	0.042	200	1.41	1.00	0.60
5000	0.01	2.2	0.0225	150	1.41	1.33	0.42

TABLE 10

Nov. 25, 1969

RECEIVER OUTPUT

MICROPHONE 6" BELOW GROUND

PROJECTOR 4" ABOVE GROUND

weather
clear
temp 40's
dry

Frequency Hz	Oscilloscope Voltage Scale Volts/Div	Oscilloscope Deflection Divisions	a Voltage PP	Projector Drive Volts PP	b Filter Response In/Out	c Projector Normalizing Factor Proj. 200/Drive	column axbxcx10 Microphone Output MV
50	0.02	5.0	0.10	200	1.67	1.00	1.67
75	0.02	4.0	0.08	200	2.00	1.00	1.60
100	0.02	4.0	0.08	200	2.00	1.00	1.60
150	0.02	4.0	0.08	200	2.50	1.00	2.00
200	0.02	4.0	0.08	200	2.50	1.00	2.00
300	0.02	7.0	0.14	200	1.11	1.00	1.55
500	0.02	7.0	0.14	200	1.11	1.00	1.55
750	0.02	8.0	0.16	200	1.17	1.00	1.87
1000	0.02	8.0	0.16	200	1.00	1.00	1.60
2000	0.02	7.0	0.14	200	1.33	1.00	1.86
3000	0.02	6.0	0.12	200	1.25	1.00	1.50
4000	0.02	6.0	0.12	200	1.41	1.00	1.69
5000	0.02	5.0	0.10	200	1.41	1.00	1.41

TABLE 11

Nov. 25, 1969

RECEIVER OUTPUT

MICROPHONE 6" BELOW GROUND

PROJECTOR 6" ABOVE GROUND

weather
clear
temp 40's
dry

Frequency Hz	Voltage Scale Volts/Div	Oscilloscope Deflection Divisions	a Voltage PP	Projector Drive Volts PP	b Filter Response In/Out	c Projector Normalizing Factor Proj. 200/Drive	column axbxcx10 Microphone Output MV
50	0.02	5.0	0.10	200	1.67	1.00	1.67
75	0.02	5.0	0.10	200	2.00	1.00	2.00
100	0.02	5.0	0.10	200	2.00	1.00	2.00
150	0.02	6.0	0.12	200	2.50	1.00	3.00
200	0.02	5.0	0.10	200	2.50	1.00	2.50
300	0.05	4.0	0.20	200	1.11	1.00	2.22
500	0.05	4.0	0.20	200	1.11	1.00	2.22
750	0.02	8.0	0.16	200	1.17	1.00	1.87
1000	0.02	8.0	0.16	200	1.00	1.00	1.60
2000	0.02	8.0	0.16	200	1.33	1.00	2.13
3000	0.02	7.5	0.15	200	1.25	1.00	1.87
4000	0.02	6.0	0.12	200	1.41	1.00	1.69
5000	0.02	6.0	0.12	200	1.41	1.00	1.69

TABLE 12

Dec. 2, 1969

RECEIVER OUTPUT

MICROPHONE 12" BELOW GROUND

PROJECTOR ON GROUND

weather
clear
temp 30's
dry

Frequency Hz	Voltage Scale Volts/Div	Oscilloscope Deflection Divisions	a Voltage PP	Projector Drive Volts PP	b Filter Response In/Out	c Projector Normalizing Factor Proj. 200/Drive	column axbxcx10 Microphone Output MV
50	0.01	3.5	0.035	350	1.67	0.572	0.33
75	0.01	3.6	0.036	800	2.00	0.250	0.18
100	0.01	3.8	0.038	800	2.00	0.250	0.19
150	0.01	4.6	0.046	800	2.50	0.250	0.29
200	0.01	5.6	0.056	800	2.50	0.250	0.35
300	0.02	5.5	0.110	800	1.11	0.250	0.31
500	0.02	1.8	0.036	800	1.11	0.250	0.10
750	0.05	2.6	0.130	800	1.17	0.250	0.38
1000	0.05	2.0	0.100	800	1.00	0.250	0.25
2000	0.05	2.0	0.100	800	1.33	0.250	0.33
3000	0.02	3.2	0.064	800	1.25	0.250	0.20
4000	0.02	2.8	0.056	800	1.41	0.250	0.20
5000	0.02	2.0	0.040	600	1.41	0.333	0.18

TABLE 13

Dec. 2, 1969

RECEIVER OUTPUT

MICROPHONE 12" BELOW GROUND

PROJECTOR 2" ABOVE GROUND

weather
clear
temp 35° F
dry

Frequency Hz	Oscilloscope Voltage Scale Volts/Div	Oscilloscope Deflection Devisions	a Voltage PP	Projector Drive Volts PP	b Filter Response In/Out	c Projector Normalizing Factor Proj. 200/Drive	column axbxcx10 Microphone Output MV
50	0.01	4.2	0.042	350	1.67	0.571	0.40
75	0.01	4.2	0.042	800	2.00	0.250	0.21
100	0.01	4.6	0.046	800	2.00	0.250	0.23
150	0.02	2.4	0.048	800	2.50	0.250	0.30
200	0.02	2.6	0.052	800	2.50	0.250	0.32
300	0.05	2.0	0.100	800	1.11	0.250	0.28
500	0.02	4.0	0.080	800	1.11	0.250	0.22
750	0.02	4.8	0.096	800	1.17	0.250	0.28
1000	0.05	2.0	0.100	800	1.00	0.250	0.25
2000	0.05	2.0	0.100	800	1.33	0.250	0.33
3000	0.05	1.8	0.090	800	1.25	0.250	0.28
4000	0.05	2.0	0.100	800	1.41	0.250	0.35
5000	0.02	3.0	0.060	600	1.41	0.333	0.28

TABLE 14

Dec 2, 1969

RECEIVER OUTPUT

MICROPHONE 12" BELOW GROUND

PROJECTOR 4" ABOVE GROUND

weather
clear
temp 25°
windy, dry

Frequency Hz	Oscilloscope Voltage Scale Volts/Div	Oscilloscope Deflection Divisions	a Voltage PP	Projector Drive Volts PP	b Filter Response In/Out	c Projector Normalizing Factor Proj. 200/Drive	column axbxcx10 Microphone Output MV
50	0.01	2.5	0.025	300	1.67	0.667	0.28
75	0.01	3.8	0.038	625	2.00	0.320	0.24
100	0.01	4.4	0.044	800	2.00	0.250	0.22
150	0.02	3.5	0.070	800	2.50	0.250	0.44
200	0.02	3.8	0.076	800	2.50	0.250	0.47
300	0.05	2.0	0.100	800	1.11	0.250	0.28
500	0.02	6.0	0.120	800	1.11	0.250	0.33
750	0.02	6.0	0.120	800	1.17	0.250	0.35
1000	0.05	3.0	0.150	800	1.00	0.250	0.37
2000	0.05	2.6	0.130	800	1.33	0.250	0.42
3000	0.05	2.4	0.120	800	1.25	0.250	0.37
4000	0.02	6.8	0.136	800	1.41	0.250	0.48
5000	0.02	5.0	0.100	600	1.41	0.333	0.47

TABLE 15

Dec. 2, 1969

RECEIVER OUTPUT

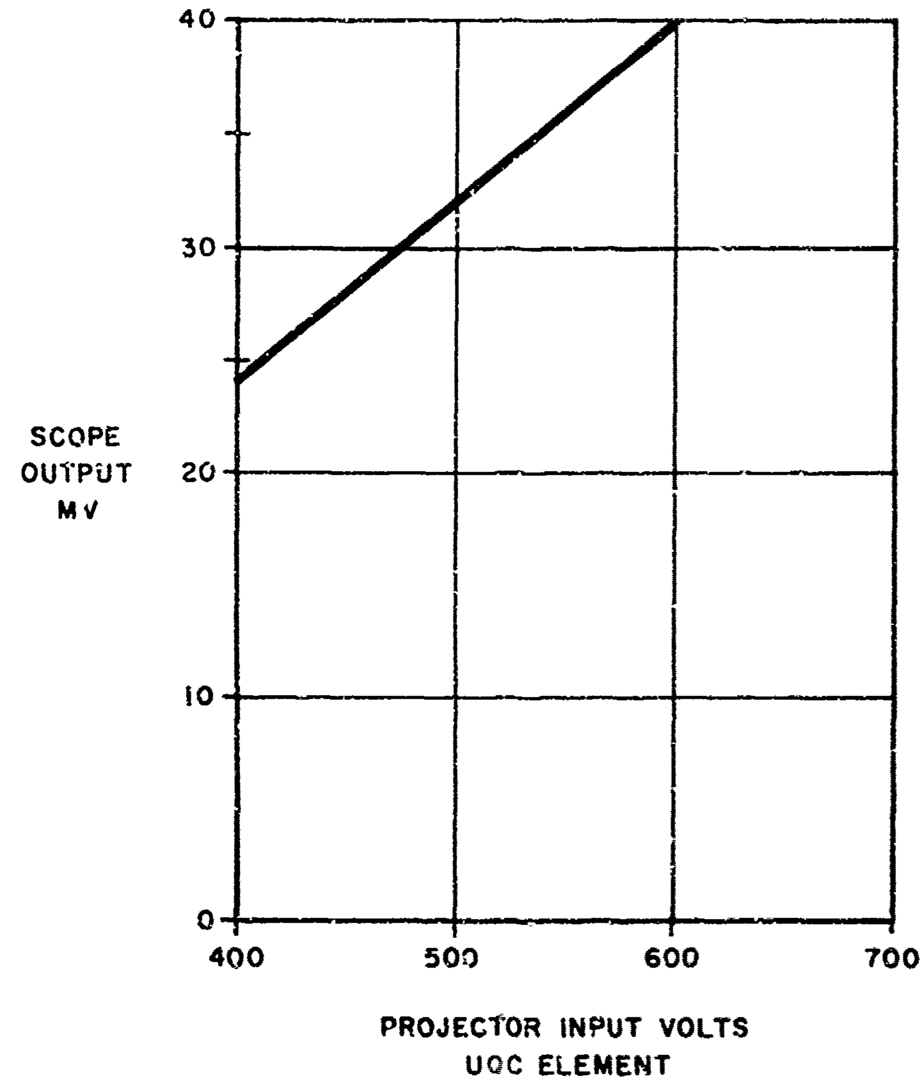
MICROPHONE 12" BELOW GROUND

PROJECTOR 6" ABOVE GROUND

weather
clear
temp 35°
dry

Frequency Hz	Oscilloscope Voltage Scale Volts/Div	Oscilloscope Deflection Divisions	a Voltage PP	Projector Drive Volts PP	b Filter Response In/Out	c Projector Normalizing Factor Proj. 200/Drive	column axbxcx10 Microphone Output MV
50	0.01	3.0	0.030	300	1.67	0.667	0.33
75	0.01	3.0	0.030	650	2.00	0.307	0.18
100	0.01	4.6	0.046	650	2.00	0.307	0.28
150	0.02	3.4	0.068	650	2.50	0.307	0.52
200	0.02	3.8	0.076	650	2.50	0.307	0.58
300	0.05	3.0	0.150	650	1.11	0.307	0.54
500	0.02	7.0	0.140	650	1.11	0.307	0.48
750	0.05	3.0	0.150	650	1.17	0.307	0.54
1000	0.05	3.2	0.160	650	1.00	0.307	0.49
2000	0.05	3.0	0.150	650	1.33	0.307	0.61
3000	0.05	3.0	0.150	650	1.25	0.307	0.57
4000	0.05	3.5	0.175	650	1.41	0.307	0.76
5000	0.02	6.0	0.120	600	1.41	0.333	0.56

CONDITIONS:
P⁐JECTOR ON GROUND
WEATHER: CLEAR, DRY, 30'S
DATE 12/2/69



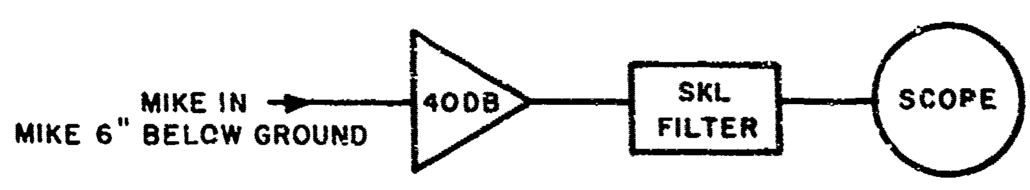


Fig A1 - Vertical Propagation Linearity at 5KHz

APPENDIX B

Propagation Loss Calculation

The propagation loss between loudspeaker and geophone is their intensity ratio I_1 (source)/I_2 (receiver):

$$\frac{I_1}{I_2} = \frac{P_1^2 / Z_1 \times 10^{-7}}{P_2^2 / Z_2 \times 10^{-7}}$$

Where P_1 = transmitted loudspeaker pressure

P_2 = geophone pressure

Z_1 = acoustic impedance at speaker (air) = $(\rho c)_1$

Z_2 = acoustic impedance at geophone (ground) = $(\rho c)_2$

ρ = density

c = sound velocity

Since the particle velocity μ at the geophone is

$$P_2 = \mu_2 Z_2$$

we have $\frac{I_1}{I_2} = (\mu_1/\mu_2)^2 \times (Z_1/Z_2)$

At a point in air 6" from the source, the particle velocity is

u_1 = 62 cm/sec

= 24.4 ips

The signal level at the geophone is

$u_2 = 1.22 \times 10^{-10}\ 1.85$

This results in a particle velocity ratio $u_1:u_2$ of $2 \times 10^{11} f^{-1.85}$

The wet soil density (tertiary kirkwood) has been measured by the Institute for Exploratory Research as 2.7 g/cc. The density of air is about 1.3×10^{-3} g/cc. This results in a density ratio $\rho_1:\rho_2$ of 4.82×10^{-4}.

The velocity of sound in air is about 344 meters/sec and in sandy soil lies between 200 - 1100 meters/sec (Heiland). Choosing a velocity ratio of 1 we have an approximate propagation loss of

$$I_1/I_2 = 2 \times 10^{19} f^{-2.7}$$

$$10 \log I_1/I_2 = 193 - 27 \log f \quad \text{(decibels)}$$
$$= 112\text{db at 1KHZ}$$

APPENDIX C

Calibration Data

Loudspeaker Calibration - Transmitted Power Level

The sound pressure level (SPL) of the loudspeaker source is specified by the manufacturer for the following conditions:

SPL = 100db ref 0.0002 dyne/cm^2
distance 100 ft.
electrical power input 100 watts

The conditions under which it was used are:

electrical drive 80VPP at 12.5Ω

electrical power input $(80/2.8)^2/12.5 = 65.1$ watts

SPL at 100' = 100 - 10 log (100/65.1) = 98.2db

SPL at $\frac{1}{2}$' = 98.2 + 20 log (100/$\frac{1}{2}$) =144.2db
re 0.0002db/cm^2

SPL at 3" = 150.2db

SPL at 1" = 159.7db

These results are summarized below.

Distance	SPL db	Pressure ratio re 0.0002 dyne/cm^2	Pressure dyne/cm^2	Velocity* cm/sec
100 ft	98.2	0.65×10^5	1.3×10	32
6 in	144.2	1.3×10^7	2.6×10^3	62
3 in	150.2	2.6×10^7	5.2×10^3	123
1 in	159.7	7.8×10^7	1.56×10^4	3710

Table C1 Sound Pressure Level

* Displacement velocity = Pressure/Acoustic Impedance of air ($\frac{42gm}{cm^2/sec}$)

Operational Amplifier Calibration

The operational amplifier and transformer response were measured and the results indicated a flat response over the band of interest 50HZ - 5000HZ with a gain of 30db and a maximum input signal of 0.2Vrms.

Geophone Calibration

Response characteristics for the geophone appear in Fig C1. They were extrapolated for the high frequencies and considered approximately flat from 300 HZ - 5000 HZ. This was confirmed by the manufacturer. A receiving response of approximately 0.3volts/ips was assumed.

When combined with the op-amp gain of 30db a voltage/ips gain of 10 results. This was the value used to determine the received particle velocity.

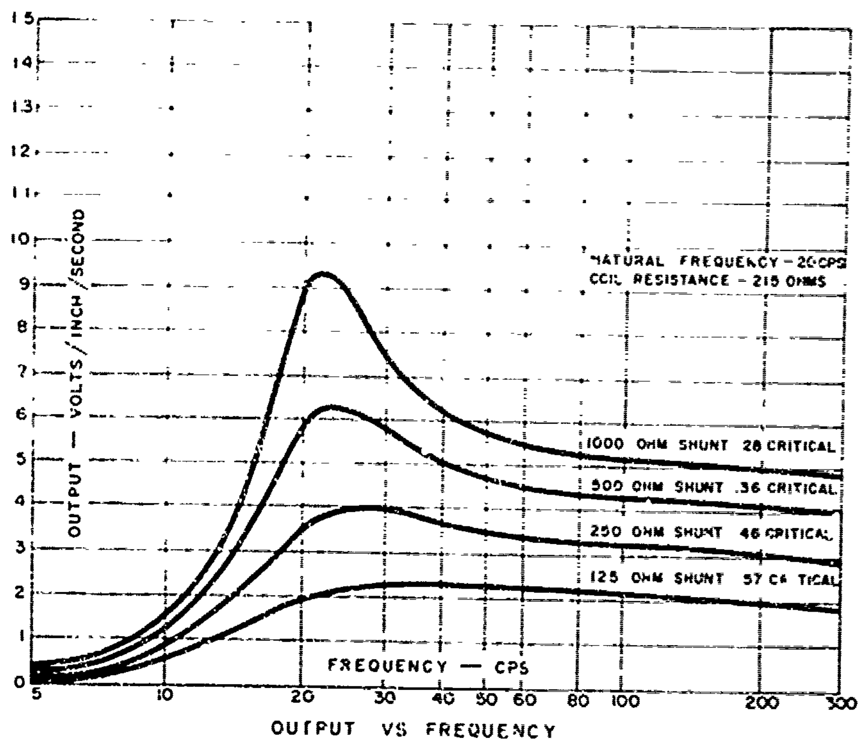


Fig. C1 Geophone Calibration.

Wave Analyzer Calibration

Wave Analyzer output voltages were converted to their equivalent input voltage by multiplying the full scale (FS) range setting by Output Amplitude control setting/Instrument Gain. The Instrument Gain (Output/Input) was measured by applying a 1VRMS, 2KHZ sine wave at the input, setting the range scale to 1VRMS and output amplitude control at F.S. The output voltage was 3 volts so that the instrument gain was 3 times. Since the output control was at 1/2 F.S. during all the measurements the Wave Analyzer output was multiplied by Range Setting/1.5.

The wave analyzer frequency response was flat within a fraction of a decibel. This response was maintained despite drift in the "normal" operating condition by frequent retuning. Direct connection to the CW source facilitated proper tuning while disconnection, no input, enabled determination of false outputs, spurious oscillations, from the wave analyzer. Operating at a slightly different frequency eliminated this error.

Table C2 Filter Response

SKL (Spencer-Kennedy Labs) Filter

Frequency Hertz	Voltage input volts PP	Voltage output volts PP	Ratio out/in	BANDPASS SETTINGS Low Pass	High Pass	Ratio in/out
50	2.0V.	1.2V.	0.60	60HZ	40HZ	1.67
75	2.0V.	1.0V.	0.50	85	65	2.00
100	2.0V.	1.0V.	0.50	110	90	2.00
150	2.0V.	0.8V.	0.40	160	140	2.50
200	2.0V.	0.8V.	0.40	210	190	2.50
300	2.0V.	1.8V.	0.90	310	290	1.11
500	2.0V.	1.8V.	0.90	510	490	1.11
750	2.0V.	1.7V.	0.85	775	725	1.17
1KHZ	2.0V.	2.0V.	1.00	1100	900	1.00
2KHZ	2.0V.	1.5V.	0.75	2100	1900	1.33
3KHZ	2.0V.	1.6V.	0.80	3100	2900	1.25
4KHZ	2.0V.	1.4V.	0.70	4100	3900	1.41
5KHZ	2.0V.	1.4V.	0.70	5100	4900	1.41

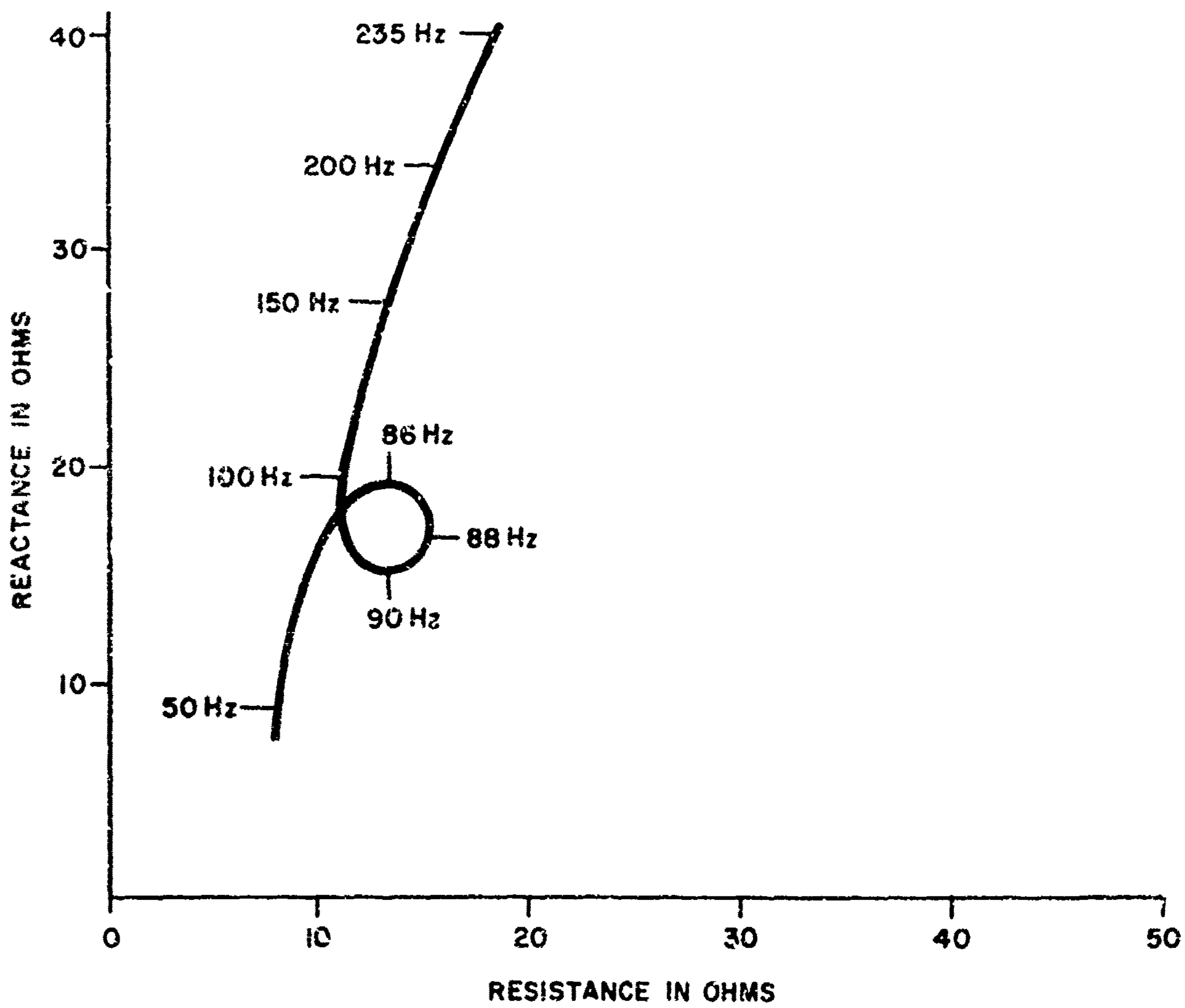
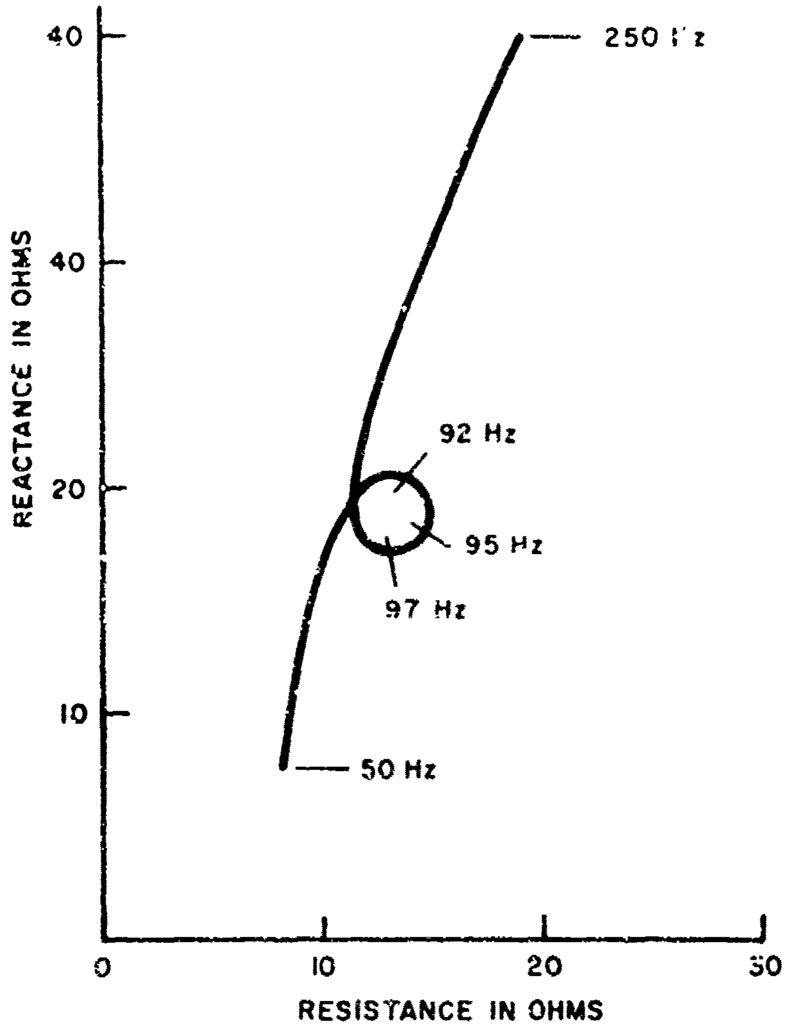


Fig. C2 Impedance of ECOM Electrodynamic Unit #1 Lying on the Ground



NOTES:
1. BLOCKED "R_S" = .0.5 OHMS
   CIRCLE DIA. = 1.5 OHMS
2. DATA INDICATES
   EFF_{MAX} OF ≅ 12 %

Fig. C3 Impedance of ECOM Electrodynamic Unit #2 Lying on the Ground

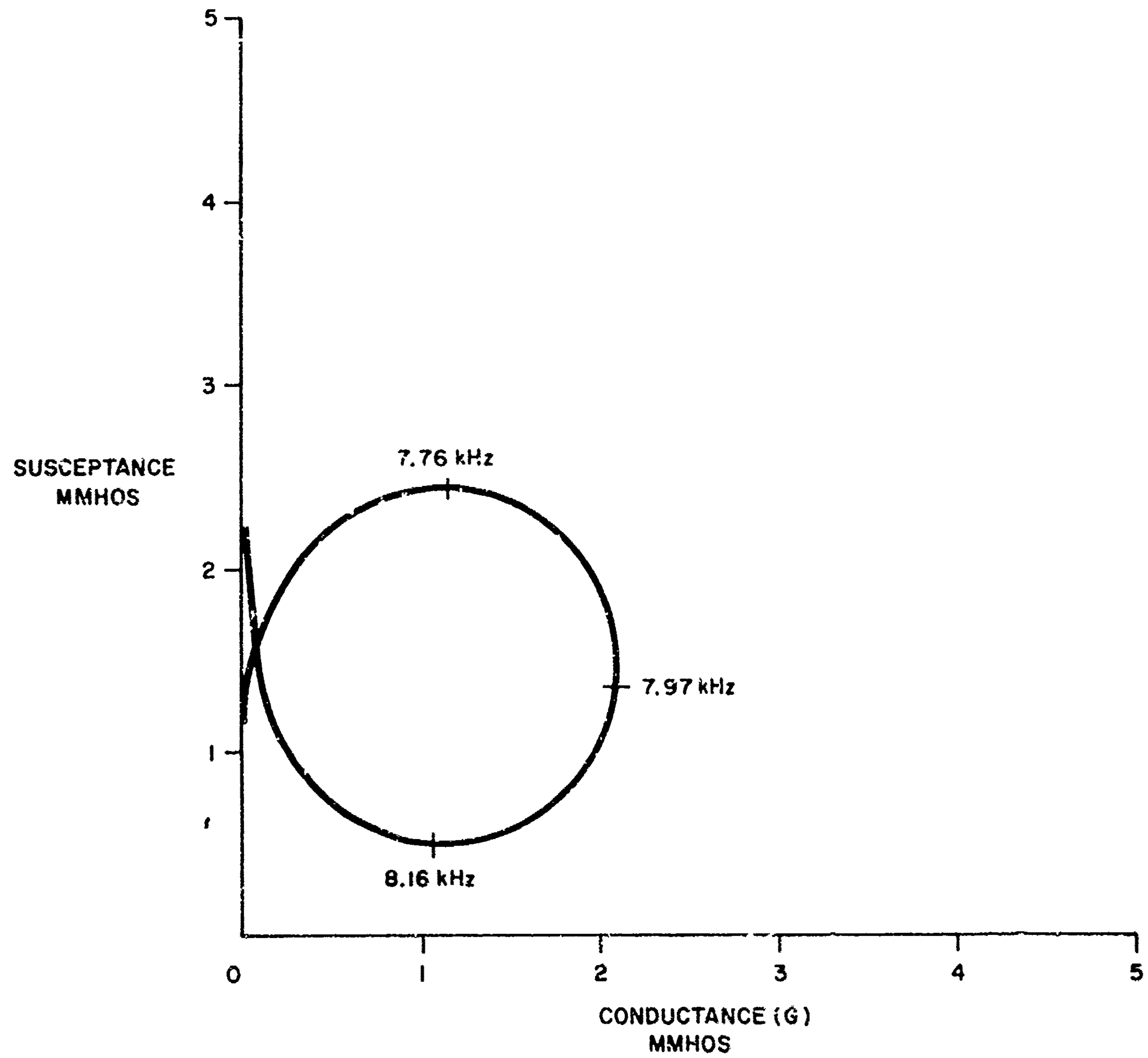


Fig. C4 Admittance of AN/UQC Transducer Element Lying on the Ground

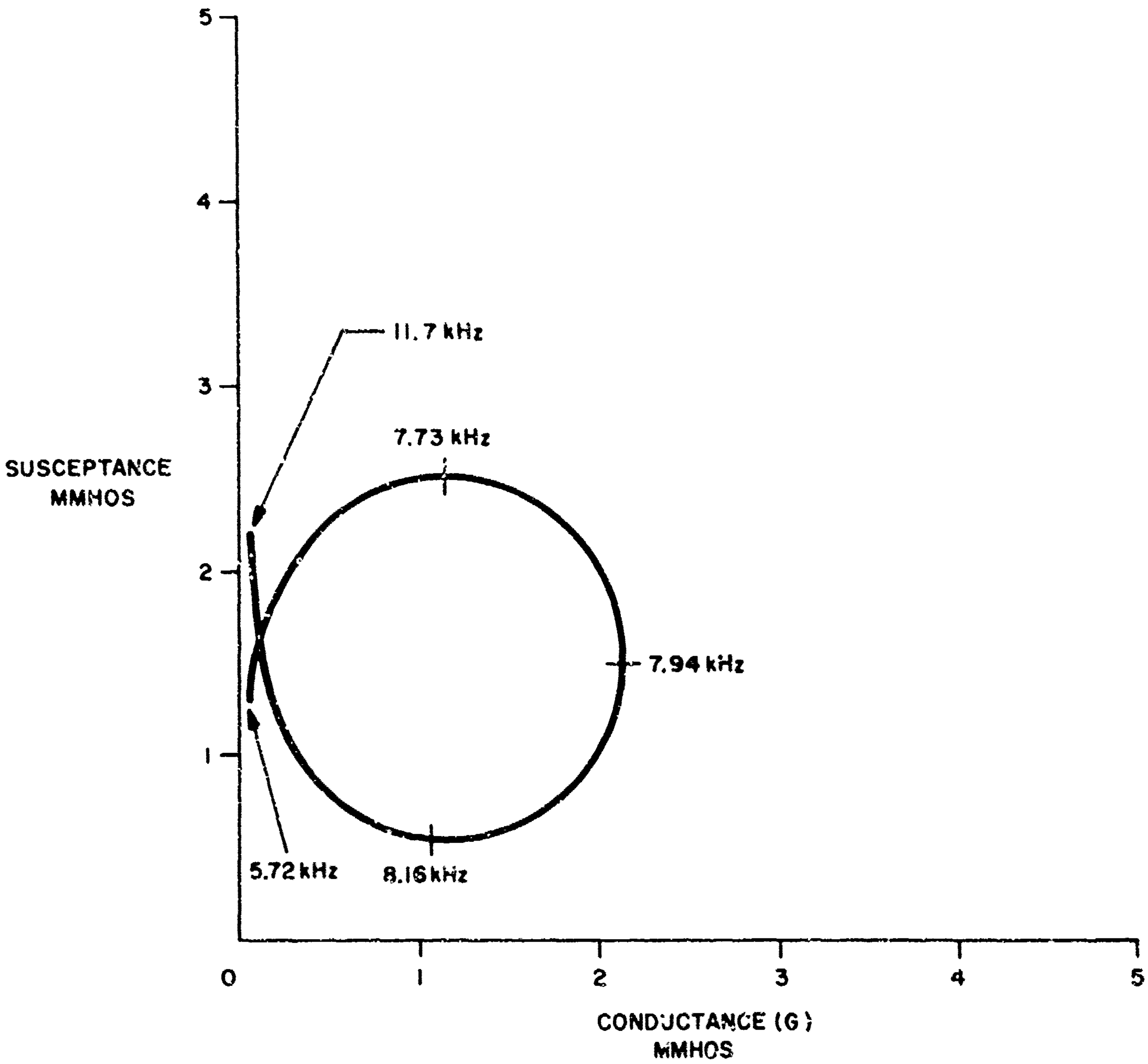


Fig. C5 Admittance of AN/UQC Transducer Element 6" above the Ground

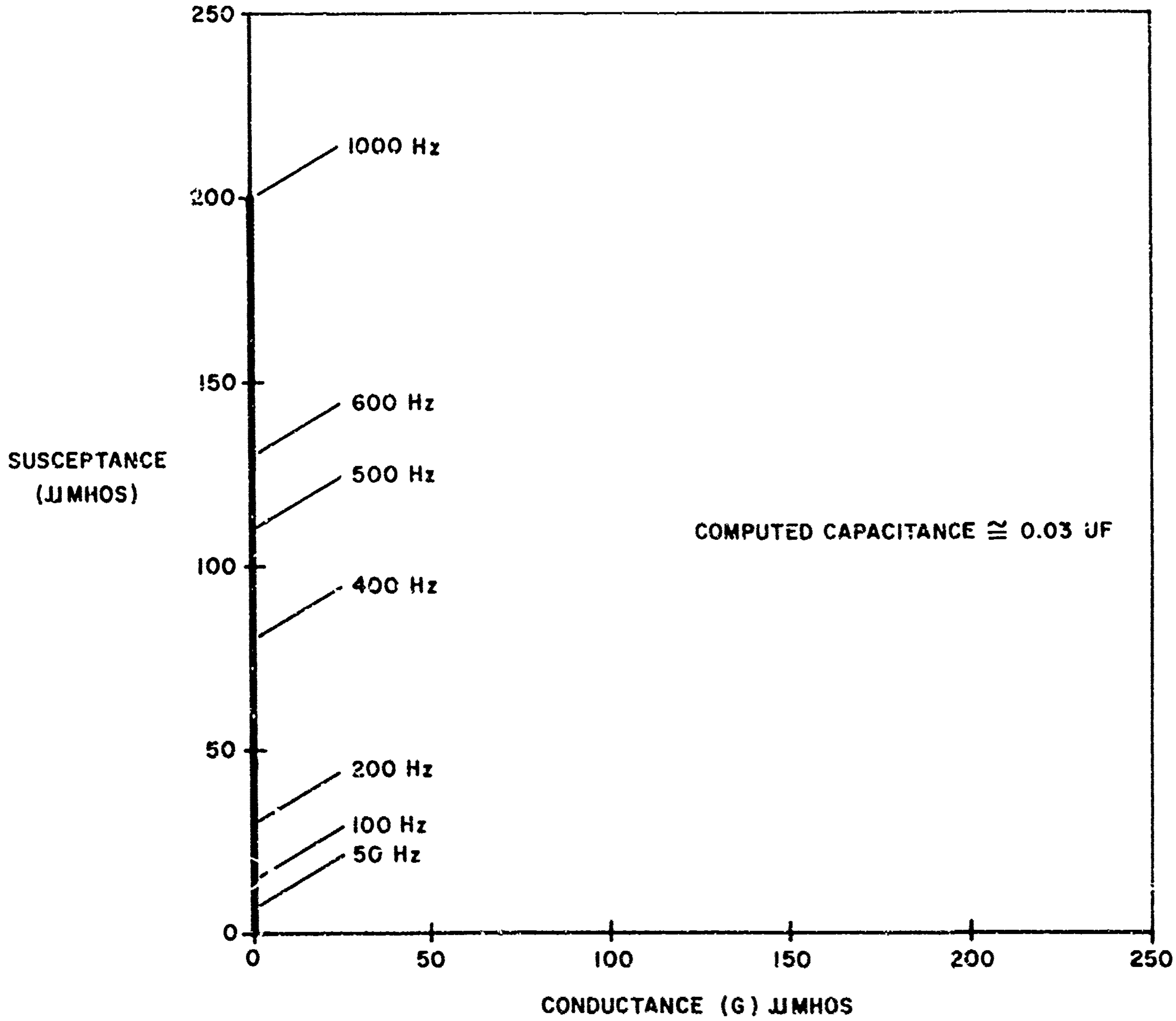


Fig. C6 Admittance of AN/UQC Transducer Element Lying on the Ground
(Frequency below Resonance)

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13. ABSTRACT

The purpose of this program was to investigate the feasibility and develop techniques for air-coupling acoustic energy into and through the soil. Acoustics, as well as mechanical probes, thermal detectors, aerial photography, infrared scanners, gravimetric anomaly, microwave radiometry and sonic techniques, have been used previously in experiments to establish their characteristics for propagation through the soil. Possible application of acoustic propagation in soil includes usage in detection, surveillance, or communications. The reason for pursuing acoustics is that until now certain key modes of propagation have been overlooked eg., the shear wave, which has great penetration capability and can sensitively respond to ground stress anomalies. This program was to investigate acoustic energy propagation with an emphasis on shear wave propagation and air-coupling for obtaining practical mobility in any intended application.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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